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JOURNAL OF THE AUDIO ENGINEERING SOCIETY

Papers from the
October 1957
Convention

VOLUME 6 NUMBER 1 JANUARY 1958

AES FOURTH LECTURE SERIES

"The Principles and Practices of Tape and Disk Recording"

SECOND GROUP OF 15 LECTURES

The Audio Engineering Society presents below the dates and titles of the balance of its Fourth Lecture Series. The enthusiastic response (more than 75 subscribers) accorded the first group of 15 lectures has so gratified its sponsors, the Lecture Series Committee, and the Board of Governors, that it is likely to become a yearly presentation.

As before, each two-hour lecture will continue to be given on consecutive Thursday evenings at 7:15 P.M. in the facilities generously contributed by the RCA Institutes, Inc., 350 West Fourth Street, New York City.

Further information and a descriptive brochure covering this group of lectures may be obtained from Mr. F. Sumner Hall, Lecture Series Chairman, Amityville, New York, or from the offices of the Society.

SECOND GROUP OF LECTURES — TITLES AND LECTURERS

16. Feb. 20 GOOD EQUIPMENT — BAD RECORDINGS?
Ralph A. Schlegel, Radio Station WOR

17. Feb. 27 ACCEPTED AND PROPOSED STANDARDS
W. A. Savory, Electric and Musical Industries, Ltd.

18. Mar. 6 TAPE TRANSPORT MECHANISMS
Richard H. Ranger, Rangertone, Inc.

19. Mar. 13 CARTRIDGES IN TAPE RECORDING
Bernard A. Cousino, Cousino, Inc.

20. Mar. 20 PROBLEMS OF TAPE DUPLICATING
Jack A. Bryant, Dubbings Sales Corporation, and
Trevor W. Kendall, Telectro Industries

21. Mar. 27 WHAT IS WRONG WITH TAPE RECORDING?
Trevor W. Kendall, Telectro Industries, and
Jack A. Bryant, Dubbings Sales Corporation

22. Apr. 3 THE PROCESSING OF MATRICES
Fred C. Meyer, M-G-M Records

23. Apr. 10 TEST RECORDS AND THEIR CALIBRATION
B. B. Bauer, CBS Laboratories

24. Apr. 17 THE STEREO DISC I
Jerry B. Minter, Components Corporation, and
William H. Offenhauser, Jr.

25. Apr. 24 THE STEREO DISC II
E. A. Dickinson, Westrex Corporation

26. May 1 THE EDITING OF TAPE
Joel Tall, Columbia Broadcasting System, Inc.

27. May 8 CONTACT SELECTION AND DESIGN
R. H. Gumley, Bell Telephone Laboratories, Inc.

28. May 15 NOISE SUPPRESSION IN AUDIO SYSTEMS
C. J. Auditore, Adler Electronics, Inc.

29. May 22 ARE TWO EARS REALLY BETTER THAN ONE?
J. Donald Harris, U.S.N. Medical Research Laboratory

30. May 29 GENERAL EXCHANGE OF EXPERIENCES
Moderated by Helmuth Etzold, American Foundation for the Blind

Journal of the AUDIO ENGINEERING SOCIETY

JANUARY 1958 VOLUME 6, NUMBER 1

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Date of publication February 14, 1958

Since the statements and opinions which appear in the papers published in this Journal are expressions of their respective authors, the Society can assume no responsibility for them. Where, however, there exists controversy or disagreement, the Editor invites correspondence.

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A Letter from the President

SHERMAN M. FAIRCHILD

Dear Members:

The field of audio is expanding; this, coupled with the development of stereo in new forms, gives your Society a chance to do a bigger job for its members. I would like to tell you of our problems and of our program for the coming year. I will welcome any ideas, criticisms, or comments, which you may have.

To carry out the programs which are planned, your Society needs funds for a larger budget. The quickest way to obtain increased funds is for the present members to give us the names of people interested and working in audio, who are not now members. A newsletter has been sent to you for this purpose. To further augment our resources, you will note that this issue of your JOURNAL, in common with many technical societies, carries advertising. The JOURNAL reaches a very selective list in the audio field and should be of interest to many organizations as an advertising medium.

The 1957 Convention was the most successful one held by your Society. One of the features was the availability of preprints on over half the lectures. We are proposing to provide preprints on as many of the Society's future papers as possible, and believe that the sale of these will make their preparation at least self-financing. The Mid-Season Convention will be held in Los Angeles at the Biltmore Hotel on February 26 and 27. We plan to have preprints of some of these papers, and to publish some of those papers in the issue of the JOURNAL coming out in April.

Perhaps the most important program is that of getting the JOURNAL out on time, and catching up during 1958 on the back issues. Your Editor fully appreciates the magnitude of this problem and has obtained additional assistance in order to get out the four 1958 issues on time, as well as the three back issues. The latter will be issued between the four 1958 issues, and you will therefore receive 7 issues during 1958.

This issue contains some of the papers given at the 1957 Convention. The availability of preprints and the prompt publication of papers given at the Convention have given new incentive to those who have papers to submit.

To further the service of your Society, a series of 30 lectures on audio fundamentals, "The Principles and Practices of Tape and Disk Recording," is being given in New York under the direction of our Lecture Course Chairman, Mr. Sumner Hall. I hope that these lectures can be repeated in other parts of the country and that they may form the basis of a handbook on audio engineering.

In conclusion, I would like to welcome the new Pittsburgh Section, of which Mr. Emerson Boardman is Section Secretary.

Yours very sincerely,

SHERMAN M. FAIRCHILD
President

From Your Editor

To our members:

I am sure that many of you are looking through this issue of the JOURNAL with the same questions in your minds. You may have noticed that this marks the first occasion in several years that the date of issue coincides with the actual publication date. This is also the first issue with advertising. Both "innovations", we hope, will have permanence.

It was the opinion of your newly elected Board of Governors at their most recent meeting last November that for the Society to fulfill better its function in the rapidly burgeoning area of sound recording and reproduction, its services to its members needed to grow at the same rapid pace.

Prior to this meeting, a first step in this direction had been taken. The Lecture Course, conducted by Mr. F. Sumner Hall, is already firmly established. It now numbers more than 75 subscribers, with an increase expected when the second half gets under way in February. (A schedule of lectures, with titles and dates appears on the inside front cover.)

As you will have read in Mr. Fairchild's message, two further steps were decided upon at this meeting. These were: the solicitation of advertising to augment the Society's altogether too modest resources and a plan to bring the JOURNAL up to date.

According to this plan, which is now in effect, the first number of Volume 6 will be issued in January 1958, and the succeeding numbers at quarterly intervals thereafter. To date one issue (January 1957) of Volume 5 has been sent our subscribers and members. The remaining three issues are in preparation and will be forwarded to you as soon as they are printed. Each number will appear in the interval between two successive issues of the 1958 year. In this manner, the JOURNAL will be up to date by the end of 1958. The contents of the remaining issues of Volume 5 will consist mainly of manuscripts which have been in the Editor's hands prior to the 1957 Annual Convention, whereas the Convention papers, and others received subsequent to the Convention, will be published in the 1958 issues.

I hope that this plan will meet with your approval. It seemed to us about the only method left to correct a chronic, highly embarrassing situation. I will welcome your expressions of opinion, for or against this policy. In fact, I will welcome almost any kind of expression from our members.

G. HORIUCHI

Transistorized Magnetic and Photoelectric Input Circuits for Motion Picture Projectors*

STEPHEN F. BUSHMAN†
Bell and Howell Co., Chicago, Ill.

The design of a transistor input stage to work from magnetic stripe on motion picture film through a reproduce head is described. Direct expressions for amplification of induced voltage are given, both with and without series feedback. Similar expressions are given for input impedance, and the effect of input impedance on frequency response is discussed. Photo detectors for use with optical sound tracks and with transistor amplifiers are compared, and a universal input stage using a phototransistor is shown schematically.

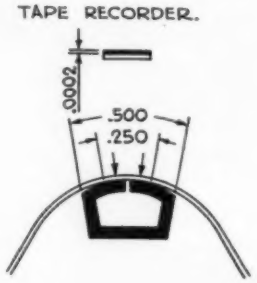
THE MAGNETIC SOUND TRACK

WITHIN THE PAST decade the art of applying coatings of magnetic materials to the sound tracks of motion picture films and magnetically recording upon and reproducing from them has been developed to a point which has resulted in widespread use of such films. 16mm film, with which this paper is particularly concerned, has been widely used for magnetic recording. 16mm film transported at the rate of 24 frames/sec has a speed of 7.2 ips, which compares with the 7.5 ips in use in magnetic tape recorders. The space available for a sound track on 16mm film is also comparable to the track widths in use in most non-professional magnetic tape recorders. A stripe width of 0.096 in. is used for "full-track" on 16mm film, which compares closely with the 0.090 in. used on popular non-professional tape recorders.

A layer of suspended iron oxide particles is commonly applied to the sound track area on 16mm film to a thickness of approximately 0.0006 in. as compared with 0.0002 in. for tape.

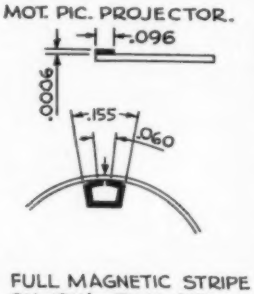
Figs. 1 and 2 show some relative dimensions of components of the magnetic systems. Included are approximate lengths of tape-to-head contact and arrows depicting direction and location of forces from pressure members, such as a roller which is used on Bell & Howell Design 302 series projectors, or pressure pads as used on tape recorders. The roller is also shown in the photograph of one of these projectors, Fig. 3. The sound drum is the cylinder at the right, above the MAG-OPT letters. The roller touches it at the lower right. The amplifier is behind the dark panel near the bottom.

When the 16mm sound track described above is recorded upon at a level of approximately 8 db below saturation, and reproduced by means of a magnetic head having a 0.090 in. track width, the curve of induced voltage *vs.* frequency at 24 frames/sec is approximately as shown in Fig. 4, and the level of induced voltage at 1000 cycles, e_1, can be at



MAGNETIC TAPE AND TAPE RECORDER HEAD.

Fig. 1



FULL MAGNETIC STRIPE ON 16 MM. FILM AND MAGNETIC HEAD ON PROJECTOR.

ARROWS SHOW DIRECTION of APPLIED FORCES.

Fig. 2

* Paper delivered at the Ninth Annual Convention of the Audio Engineering Society, New York, October 10, 1957. Paper received October 12, 1957.

† Senior Electronic Engineer.

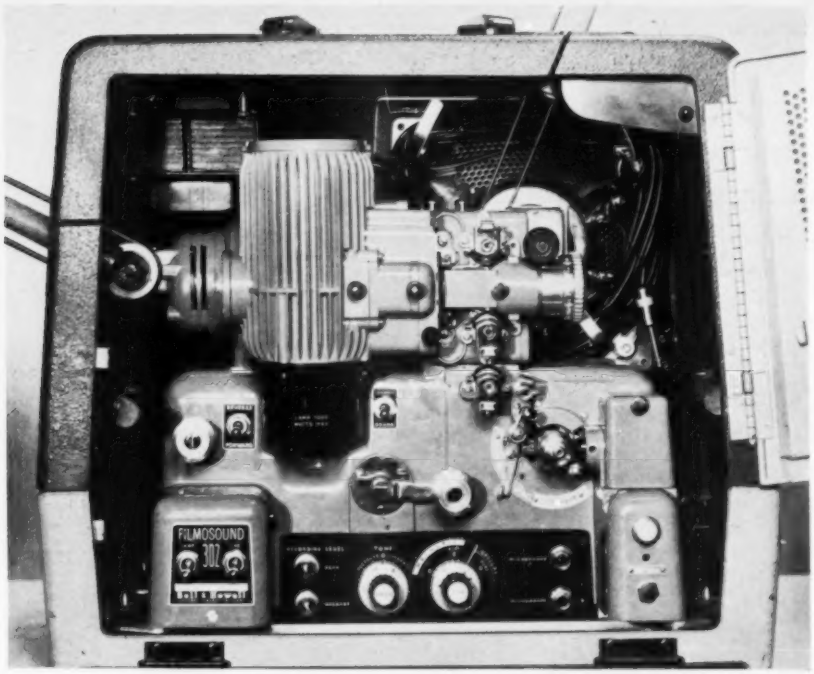


FIG. 3. View of 16mm sound projector showing location of magnetic-optical sound head and amplifier.

least roughly expressed as

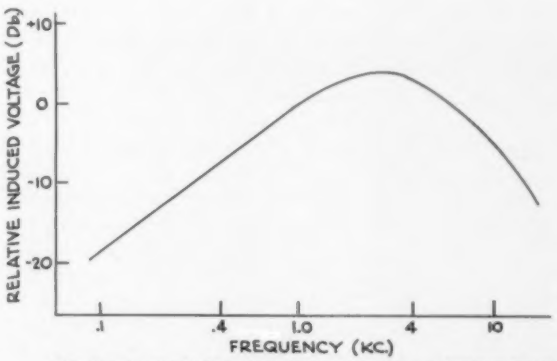
$$e_1 = 6.3 \times 10^{-5} \sqrt{Z_{b_1}}$$

where Z_{b_1} is the head impedance at 1000 cycles. This relationship applies for many practical heads having 1000 cycle impedances ranging from 10 ohms to 15,000 ohms, principally reactive rather than resistive.

In a 16mm sound projector it may not be practical or convenient to terminate the head, for reproducing, in a high impedance. One reason for this is physical layout, which may require perhaps several inches of separation between the head and the amplifier at the sound drum. When the necessity for electrostatically shielding the high impedance system to minimize noise pick-up is taken into account, it is seen that a relatively low impedance head becomes attractive.

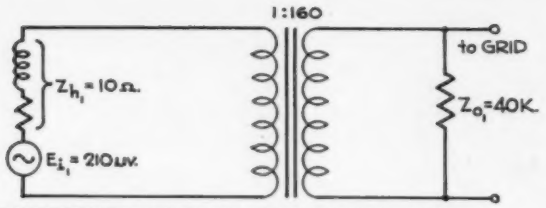
TRANSFORMER INPUT TO TUBE GRID

The preceding considerations led, in an early magnetic recording projector, to the use of the small head shown in Fig. 1, which had an impedance of 10 ohms at 1000 cycles. The head was connected through several inches of shielded cable to the primary of a 160:1 step-up transformer, which saw an impedance of approximately 40,000 ohms at 1000 cycles at the secondary side, which was the grid circuit of the first stage of a vacuum-tube amplifier. The head impedance, being largely inductive, was lower in the bass-tone region than at 1000 cycles, and the load on the secondary was also frequency dependent, although in the opposite sense. Accordingly, this arrangement provided an impedance match in the low audio range. Due to the frequency dependence of the primary and secondary impe-



RELATIVE INDUCED VOLTAGE IN HEAD VS. FREQUENCY.

FIG. 4

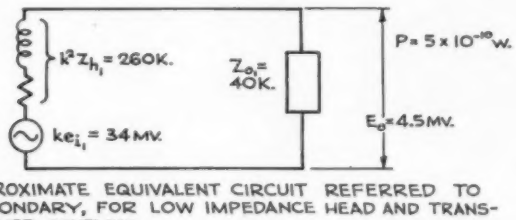


TRANSFORMER COUPLING FROM LOW-IMPEDANCE HEAD TO GRID CIRCUIT, AT 1000~.

FIG. 5

dances, it also provided the bass boost which is required of the reproducer to compensate for the curve of Fig. 4 and to yield a flat frequency response across most of the audio range.

Fig. 5 shows the transformer coupling at the output impedance Z_{o_1} and to the amplifier first grid. Fig. 6 shows an



APPROXIMATE EQUIVALENT CIRCUIT REFERRED TO SECONDARY, FOR LOW IMPEDANCE HEAD AND TRANSFORMER COUPLING.

FIG. 6

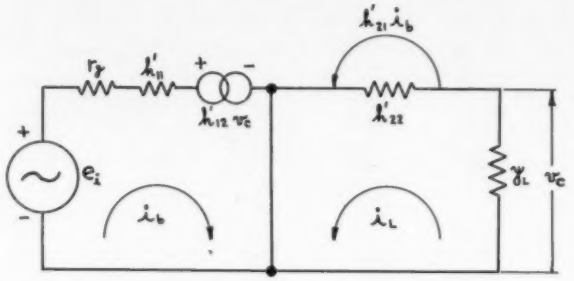
equivalent circuit consisting of the head impedance and induced voltage referred to the transformer secondary side, at 1000 cycles. It will be noted that output voltage E_o in the mid-audio range has been sacrificed in favor of some other advantages.

While this approach has been used, it is not without its drawbacks. The input transformer and attendant wiring are highly subject to pick-up of hum and other noise fields, and require careful orientation and placement; the transformer is subject to magnetic saturation leading to microphonism and distortion, and the transformer's leakage reactance reduces high-frequency response.

TRANSISTORIZED MAGNETIC INPUT CONSIDERATIONS

Designing a transistor stage to replace the input transformer calls, of course, for selection of one of the three basic transistor circuits. Since the common-emitter circuit offers more power gain than the common-base or common-collector circuits, and since the impedances with which it works efficiently are not difficult to use, it is a logical choice.

Input impedance and amplification expressions are derived from the equivalent circuit shown in Fig. 7, which shows induced voltage in the generator, or head, as e_i, causing base current flow i_b through generator impedance r_g in series with common-emitter input impedance h'_{11} and reverse voltage generator $h'_{12}v_c$. The collector current generator $h'_{21}i_b$ causes load current i_L to flow through common-emitter output impedance h'_{22} and load admittance y_L, thus generating load voltage v_L. When the h' common emitter parameters are converted to the more readily available common base parameters,[1] the expression for input impedance



EQUIVALENT CIRCUIT FOR COMMON-EMITTER AMPLIFIER

FIG. 7

to the base of the transistor shown in Fig. 8 is obtained. The subscript b is used to indicate the grounded-base parameters.

$$Z_{IN} = \frac{h_{11b}}{1+h_{21b}} + \frac{\left(h_{11b}\,h_{22b} - h_{12b}h_{21b} - h_{12b}\right)h_{21b}}{h_{22b} + y_L\left(1+h_{21b}\right)}$$

INPUT IMPEDANCE of COMMON-EMITTER STAGE WITHOUT FEEDBACK.

FIG. 8

Similarly, an expression for amplification of induced voltage can be derived, permitting the direct calculation of output voltage from circuit parameter and induced voltage values. This differs from the more commonly used voltage gain expressions, which are not useful without the preliminary step of first calculating base voltage. It also obviates the need for using the concept of transducer gain. The expression for amplification of induced voltage is shown in Fig. 9.

The case of series feedback in the stage, or emitter degeneration, is of interest. For this case, where an unbypassed resistance R_E is added in series between the emitter and the common input-output terminal, the expression $h_{11b} + R_E$ is substituted[2] for h_{11b} in the preceding expressions to obtain

[1] R. F. Shea, *Transistor Audio Amplifiers*, (John Wiley & Sons, Inc., New York, 1957), p. 85.
[2] *op. cit.*, p. 131.

$$A_V = \frac{v_L}{e_i} = \frac{\dfrac{h_{21b}}{1+h_{21b}}}{\left(\dfrac{h_{22b}}{1+h_{21b}}+y_L\right)\left(r_g+\dfrac{h_{11b}}{1+h_{21b}}\right)-\left(\dfrac{h_{11b}h_{22b}}{1+h_{21b}}-h_{12b}\right)\left(\dfrac{h_{21b}}{1+h_{21b}}\right)}$$

AMPLIFICATION of INDUCED VOLTAGE WITHOUT FEEDBACK.

FIG. 9

corresponding expressions for input impedance and amplification of induced voltage, both with feedback. The expressions are shown in Fig. 10 and Fig. 11, respectively.

$$Z_i = \frac{(h_{11b}+R_e)(h_{22b}+y_L)-h_{12b}h_{21b}}{h_{22b}+y_L(1+h_{21b})}$$

INPUT IMPEDANCE of COMMON-EMITTER STAGE WITH FEEDBACK.

FIG. 10

In designing the transistor stage to work with an input device such as a magnetic head, in which both the generated voltage and the internal impedance of the generator are frequency dependent, one of the first choices which must be made is to decide upon the frequency at which an impedance match between generator and load is to be obtained. If the match is made at low frequencies, then power transfer from head to transistor is relatively poor in the upper frequency range, and considerable equalizing is required later on in the amplifier to make up for loss of high frequencies due to the head-to-load mismatch. Making the match in the middle of the frequency range is a good compromise where the ratio of input signal power to transistor or circuit noise power is critical.

$$A_V = \frac{\dfrac{h_{21b}}{1+h_{21b}}}{\left(\dfrac{h_{22b}}{1+h_{21b}}+y_L\right)\left(r_g+\dfrac{h_{11b}+R_E}{1+h_{21b}}\right)-\left[\dfrac{(h_{11b}+R_E)h_{22b}}{1+h_{21b}}-h_{21b}\right]\left(\dfrac{h_{21b}}{1+h_{21b}}\right)}$$

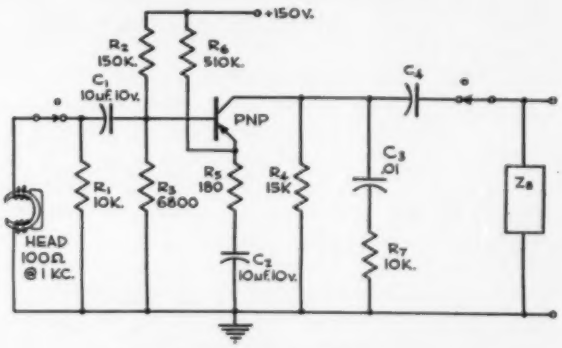
AMPLIFICATION of INDUCED VOLTAGE WITH FEEDBACK.

FIG. 11

However, if, as in the case to be described, a minimum of high-frequency boosting in the later stages of the amplifier to secure a flat response is desired, then the use of a rather high input impedance in the transistor stage as compared with the head impedance over most of the audio range is indicated.

PRACTICAL MAGNETIC INPUT CIRCUIT

The result of such an approach is shown in Fig. 12. The small head structure shown in Fig. 1 is used, with enough turns of fine wire (approximately 600 turns of #43) wound on it to produce a head impedance of approximately 100 ohms, mostly reactive, at 1000 cycles. The output of the head is fed to the base of a common-emitter stage which has an input impedance of approximately 3000 ohms throughout the audio range of interest. Accordingly, since the head impedance is less than 1000 ohms at 10,000 cycles, the loss in voltage at the base of the transistor, due to the loading effect of input impedance, is negligible at the low audio frequencies and somewhat less than 3 db at 10,000 cycles.



MAGNETIC INPUT STAGE.

FIG. 12

The relatively high input impedance exhibited, for a common-emitter stage, is due to the combined effect of the inclusion of the series feedback resistor R_5 and of operating the transistor at the relatively low bias point of 0.3 ma. emitter current and 3 volts collector-to-base.

The ac feedback amounts to approximately 8 db. This relatively large amount is used more for reasons of reproducibility than for its effect on increasing input or output impedance. However, it has the virtue of accommodating transistors with base current gains ranging all the way from 0.9 to the highest values common in junction transistors, with relatively minor effects on gain and frequency response. The feedback has an adverse effect on signal-to-noise ratio, since it attenuates the signal more than it does the transistor noise. However, by specifying transistors with a maximum of 12 db noise figure, and through the use of low-noise deposited-carbon biasing resistors, amplifier noise is kept to 55 db or more below signal level.

Bass boost is required to compensate for the 6 db-per-octave characteristic of induced voltage in the lower part

of the audio passband, and about 5 db of a total requirement of about 20 db is provided by means of the network R_4, R_7 and C_3, in conjunction with the transistor's output impedance. The remainder of the bass boost is provided at a higher level in the amplifier, where there is little danger of degrading the signal-to-noise ratio.

The "reproducer" frequency response of the transistor stage, for a constant induced voltage in the head, is about +5 db at 100 cycles and –3 db at 10,000 cycles, both with respect to 1000 cycles. When induced voltage varies as in Fig. 4, that is, on a typical play-back, the output is about –15 db at 100 cycles and about –8 db at 10,000 cycles. The amplification of induced voltage is about 24 times at 1000 cycles, so that the output level is about 15 mv at 1000 cycles. For comparative purposes, this is about 3.5 times the voltage level and about 5000 times the power level provided by the transformer arrangement, at the same frequency.

A very high degree of bias stabilization is employed. The availability of a 150 volt dc supply allows the use of a biasing circuit with a stability factor of 1.01 and assures operation to 65°C or higher.

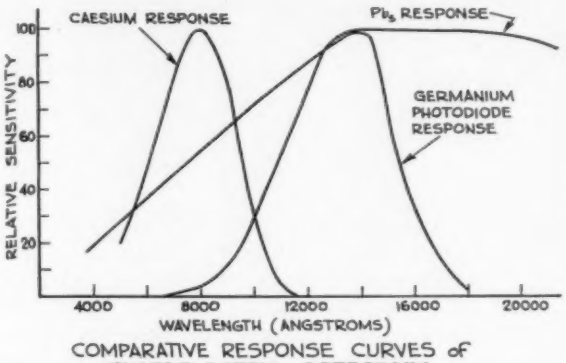
To summarize results with the transistor input stage as compared with the transformer arrangement, it can be said that the change is a highly satisfactory one. Signal-to-noise ratios from film are improved by at least 10 db, high-frequency response is markedly improved, and troubles due to microphonism and critical location of leads and components have disappeared. Production experience with this formerly critical part of the amplifier has been good from the start of transistorized production, now dating back many months, and field performance is excellent.

PLAYBACK OF OPTICAL RECORDINGS

Let us now take a look at the optical sound track and playback of its record through the medium of transistors, phototransistors, or photo-diodes.

First, an examination of the amount of signal power ordinarily received with typical 16mm sound optics and detector. The output of a cesium-oxide gas phototube in the presence of average light excitation, modulated by a 16mm film sound-track, and working into a typical load, can be roughly represented as equivalent to a 0.25 volt generator of 20 megohms internal impedance working into 2 megohms. In this case the phototube is delivering 23 mv to 2 megohms, or 2.6 x 10^{-10} watts. This is in the same order of magnitude as the power taken from the magnetic head by the transistor stage previously described, at the center of the audio band. However, in the case of the transistor stage previously described, the input impedance was about three orders of magnitude lower than the two megohms just mentioned. Accordingly, it would not make an efficient load for a photo-emissive tube. While it is possible to produce input impedances of the order of a megohm or more with a transistor, there are practical limitations which lead one to examine other possible photocell-amplifier arrangements.

The lead-sulphide cell is in use in 16mm optical sound projectors. It is operated with loads of the order of 100,000 ohms and can be made for lower impedances. It offers a good signal-to-noise ratio and freedom from microphonics. Its response curve is peaked in the infra-red region, which is advantageous in some respects, but depressed in the visible region, as shown in Fig. 13. The cell develops considerable



COMPARATIVE RESPONSE CURVES of PHOTOELECTRIC DETECTORS.

FIG. 13

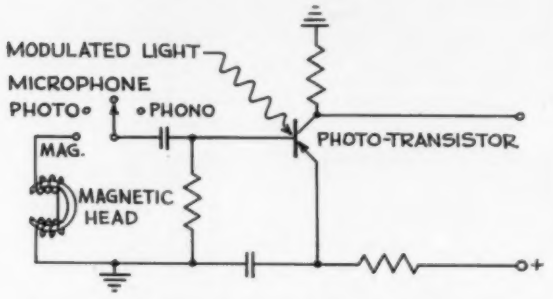
second-harmonic output if the output voltage is allowed to be high.

PHOTOTRANSISTORS

The phototransistor is a combined photocell and signal amplifier. Germanium phototransistors have been introduced by a few transistor manufacturers, principally with a view toward headlight dimming applications. They produce voltage outputs at a 10,000 ohm level which are comparable with the cesium-oxide gas phototube output at 2 megohms, and consequently have much higher signal power output than do the phototubes. Their frequency response is adequate for audio-frequency use, and the signal-to-noise ratio of some samples at least is near to that obtained with the cesium cell.

Perhaps the main objections to use of the phototransistor in motion picture sound applications are that it is a rather low-manufactured-volume item at present and that it is subject to geometric distortion. The latter term refers to the fact that the sensitive area is small, and that output is

thus a strong function of the exact location of the light spot. Another objection is that its chief response is in the infra-red rather than the visible spectrum, and that it, therefore, tends to suffer from low output and poor signal-to-noise ratio when used with colored dye tracks. However, this property is shared by other photocells, and, as with them, the signal-to-noise ratio is subject to improvement through the use of filters. A universal amplifying input stage for optical, magnetic and other inputs is possible through the use of the phototransistor, as shown in Fig. 14.



UNIVERSAL INPUT USING PHOTO-TRANSISTOR.

FIG. 14

Photodiodes have been introduced in the point-contact form and in small-area and large-area forms. Their lack of amplification, as compared with the phototransistor, is made up, to some extent at least, by the use of higher load resistance. They are in general subject to the same objections as are phototransistors. However, the broad-area photodiode in which light is focused on a plane crystal surface near but not on the junction is less subject to geometric distortion, and may provide an answer to a need in the motion picture industry for better low-impedance photocells to work into transistor amplifiers.

Acknowledgment

Acknowledgment is made of helpful data obtained from several associates of the writer, including particularly Messrs. John S. Powers and Roy H. Watterlohn.

THE AUTHOR

Stephen F. Bushman was born in Aurora, Illinois in 1913. He received the BS in EE degree from the University of Illinois in 1939. He was employed in television receiver development by Zenith Radio Corp. from 1939 to 1942 and in fixed radio facilities planning and installation by the U. S. Army Signal Corps during 1942 and 1943. From 1943 to 1946 he was in charge of electronic circuit design for radar trainers and television for Bell & Howell Company. He was a project engineer on television receiver and computer work for Belmont Radio Corp. from 1946 to 1949, and a liaison and circuit development engineer on computer and electronic instrument work for A. C. Nielsen Co. from 1949 to 1952. Since 1952 he has specialized in semiconductor circuit development for Bell & Howell Company. Mr. Bushman is a registered professional engineer in Illinois.

Portable Transistor Music System*

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Minneapolis-Honeywell, Boston Division

A transistor power amplifier circuit has been developed in which all transformers and interstage coupling capacitors have been eliminated by dc coupling, even to the loudspeaker. Its transistor output stage is operated in push-pull class B and delivers 20 watts from a standard 45-volt battery and four mercury flashlight cells. The amplifier uses 13 transistors.

Because of its excellent overload characteristics the amplifier is capable of producing listening levels, with unnoticeable distortion, equivalent to the output of a 100-watt amplifier. Distortion below the overload point is held to an extremely low value by means of 60 db of feedback around eight stages.

The power amplifier is installed together with batteries, a tone control preamplifier unit, and an efficient 15-inch woofer and horn tweeter combination in a 2.3 cubic foot cabinet. Contrary to usual practice, the enclosure is deliberately made highly reverberant.

The tone control preamplifier has 11 transistors, operates on self-contained batteries, and may be used as a remote controller. It incorporates a four-channel mixer, provision for monitoring from tape while recording, a magnetic phono pickup preamplifier, tone controls, and equalization for the acoustic response of the speaker system. Noise and distortion are extremely low.

This entire system is designed to operate at ambient temperatures from 0 to 125 degrees Fahrenheit. Its total weight is 57 pounds. For easy portability the cabinet is equipped with a handle and wheels.

THE POWER AMPLIFIER

THE POWER AMPLIFIER is constructed in an 8" x 6" x 3½" aluminum chassis box as shown in Fig. 1. The 55-watt power transistors used in the output stage are mounted toward the left front on a bracket which conducts their heat to the main chassis. Not shown are the external batteries which are somewhat larger than the chassis itself.

This amplifier is designed to deliver 20 watts to an 8-ohm load. It has a flat voltage gain of 30 db and an input impedance of 3.3K. An input of 0.4 volt rms will drive the amplifier to its full 20-watt output. The only controls are two push-buttons for turning the amplifier on and off. Three screwdriver-operated potentiometers permit adjustment of the average no-signal collector current in the output transistors, and their dc and ac collector current balances.

The entire design is predicated upon its being used for the reproduction of speech and music wherein the average power input in the course of an hour is perhaps only 1/50 of the peak power input. This low average-power input allows a battery life of from 10 to 100 operating hours, depending upon how loudly the music is played.

With load impedances higher than 8 ohms less power and current are delivered to the load, and the size and weight of the batteries to supply this power can be reduced accordingly. There is an economical limit to reduction of the size

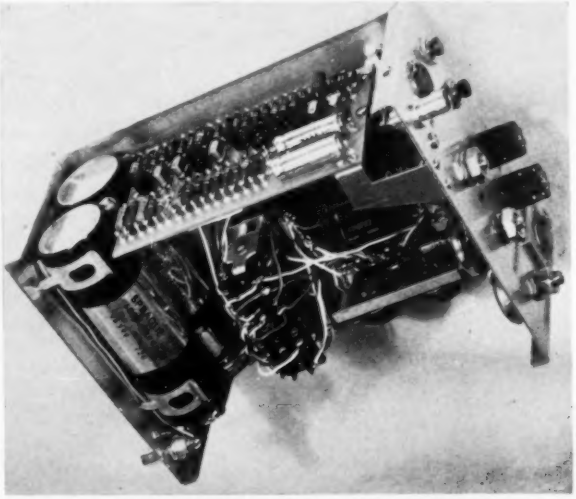

FIG. 1. 20-watt transistor power amplifier.

* Paper presented at the Ninth Annual Convention of the Audio Engineering Society, New York, October 10, 1957. Paper received October 12, 1957.

of the batteries in cases where long life is not needed. When the batteries are too small their internal resistances are so high that more power is lost in the batteries than is delivered to the amplifier. The batteries used in this music system, where the power amplifier is installed in the speaker cabinet, weigh about 13 pounds.

When reproducing music and speech the average power input is so low and the efficiency is so high (69 per cent at maximum sinusoidal output) that there is practically no heating of the chassis. An appreciable temperature rise does occur at a number of the transistor junctions. At chassis ambient temperatures up to 125°F. these junction temperatures are maintained well within ratings. The amplifier is capable of a sustained sinusoidal output of 20 watts; but there is some chassis heating and battery life is very short. Above 5 kc the power stage is less efficient and, after a few minutes of sustained full power output, there is a tendency toward overheating of the output transistors. Since this heating does not occur in normal sound reproduction, it is not important. Stability of each output transistor's operating point with temperature variations is achieved through dc feedback and diode temperature compensation.

While the amplifier is capable of delivering 40-watt undistorted peaks to the loudspeaker, under overload conditions it is capable of producing an average loudness level equal to that of an amplifier 3 to 20 times as powerful, depending upon how much distortion can be tolerated. When listening to reproduced speech the ear does not notice the absence of occasional large peaks that are clipped off due to inability of the amplifier to deliver more than 42 watts peak at the limit of its output. Overloading or speech clipping is standard practice in military communications equipment. Reasonably clean reproduction can be obtained provided the high frequencies are rolled off at some point following the clipping to attenuate the harmonic distortion. In this case the speaker system rolls off the high frequencies. Using this technique it is possible to increase the average output (beyond the overload point on occasional peaks) as much as 10 db on speech and five db on music. The maximum increase in average output, when the amplifier is putting out square waves nearly all the time, is about 13 db.

With ordinary r-c coupled amplifiers this speech-clipping technique is not very successful. After a peak has been clipped the charge on its coupling capacitors prevents the amplifier from returning to its normal state in time to allow smaller peaks to pass undistorted. The sound is muddy and distorted, particularly from amplifiers that have extreme low-frequency response. With the direct-coupled circuit used in this transistor amplifier recovery from overload is practically instantaneous. Hence the full benefit of the clipping technique can be realized; the 20-watt amplifier can be made to sound like a 60-watt amplifier on music or a 200-watt amplifier on speech.

Circuit

The method of direct-coupling 13 transistors in the power-amplifier circuit is shown in Fig. 2. Q1, the input transistor, is a *pnp* emitter-follower for the purpose of providing low noise, a high input impedance and a low output impedance. This low impedance source feeds the low input impedance of the grounded-emitter *pnp* amplifier, Q3. This stage has a very high voltage gain of over 2000. Its high gain is obtained by using an extremely high collector load impedance consisting of the collector impedance of an *npn* transistor, Q2. In order to minimize the loading on Q3 and to provide a low output impedance, the next two stages, Q4 and Q5, are *pnp* emitter-followers.

This combination of one grounded-emitter stage and three emitter-followers provides high gain at low frequencies, with phase shift at extreme high frequencies equal to that of only one stage. In the megacycle region, which has to be considered when a large amount of feedback is used, the emitter-followers pass the signal directly through their base-to-emitter capacitances with little phase shift.

At the output of Q5 the dc level is reduced to approximately ground potential by a voltage divider between Q4 and Q5. Q5 then feeds four stages of push-pull class-B amplification. Dc levels are handled by using both *pnp* and *npn* transistors. There is no connection between the sides of the push-pull stages except at the common input and at the common output. The output stage utilizes two 55-watt power transistors, both of the *pnp* type.

The lineup which allows direct-coupled push-pull operation of the output stage is as follows. The upper half-circuit is supplied by a 22.5-volt battery and consists of two grounded-emitter stages, Q6 and Q7, followed by two emitter-follower stages, Q8 and Q12. The lower half-circuit is supplied by a 22.5-volt battery and consists of a grounded-emitter stage, Q9, followed by two emitter-follower stages, Q10 and Q11, and a final grounded-emitter stage, Q13. The collector of the grounded-emitter stage, Q13, is connected to the emitter of emitter-follower, Q12, to deliver a 2.2-ampere peak push-pull output signal. There are two stages that invert phase in each half-circuit and two stages that do not. The difference in sequence makes it possible to use high power *pnp* transistors of the same type in each half of the output stage.

Following the signal along more closely, the base inputs of the complementary-symmetry grounded-emitter transistors, Q6 and Q9, are connected essentially in parallel through two diodes which are used for biasing. Their out-

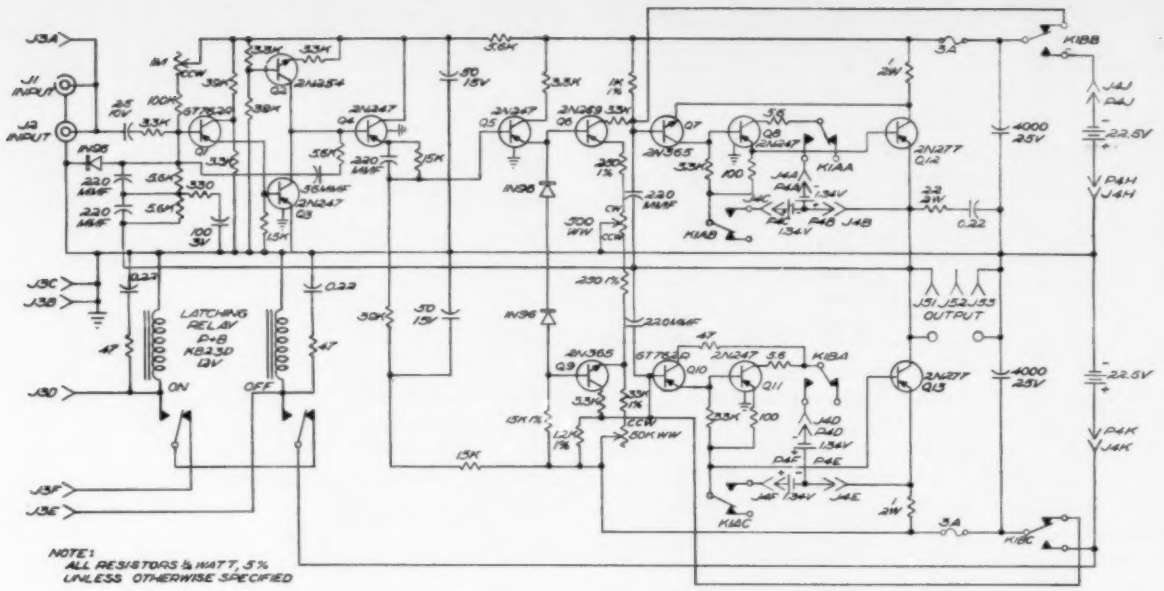

FIG. 2. Circuit diagram of power amplifier.

puts are separate, but in-phase. Q6, a *pnp* transistor, has a negative no-signal collector potential and it conducts only when the incoming signal is negative. Q7, a *npn* transistor, has a positive no-signal collector potential and it conducts only when the incoming signal is positive. To prevent crossover distortion the bias is set so that there is a small overlap region during which both transistors deliver output signals.

The voltage gain of each transistor is stabilized at 2 by means of a large amount of emitter degeneration which also reduces distortion. Q6 then feeds the 3-stage feedback amplifier combination, Q7, Q8, and Q12. The *npn* grounded-emitter transistor, Q7, actually produces the output voltage at its collector. Emitter-followers, Q8 and Q12, serve only to increase the output current at the same voltage. Since the collector of Q7 swings at the output voltage, Q7 has to be specially selected for 40-volt operation. In order to be able to use a low-power, wide-band transistor, Q8, to supply 100 ma peak driving signal to Q12, the dc power for Q8 is supplied by two, separate, 1.3-volt cells that float at the potential of the output signal. Each transistor conducts only on the same half-cycle as Q6.

The current gain from the input of Q7 to the output of Q12 is stabilized at 1000 by feedback. This feedback voltage is developed across a 1-ohm resistor in series with the emitter of Q7 by the collector output current of Q12. Since this feedback is produced by current in the load, the output impedance is very high and the voltage gain is proportional to the load impedance. With an 8-ohm load the voltage gain is 8.

In the lower half-circuit the operation is a little different. Q10 and Q11 are low-voltage emitter-followers operating from two 1.3-volt cells connected to the emitter of Q13. Q13 is the only transistor operating with large collector voltage swings. Each transistor conducts only on the same half-cycle as Q9 (with a small overlap region). Negative current feedback is developed across a 1-ohm resistor by the emitter current of Q13 and fed in series with the small base-emitter voltage of Q11 to the emitter of Q10. There is enough feedback to stabilize the current gain at 1000. The linearity of the lower half-circuit is not as good as in the upper half-circuit because the base-emitter voltage of Q11 is non-linear.

Since the voltage gain from the inputs of Q6 and Q9 to the output is 16 in each case, and is stabilized by feedback, the output signals are equal and low-distortion push-pull operation results. A vernier adjustment on the signal balance is included in the emitter circuits of Q6 and Q9 to take care of tolerances in the components.

Protection against short circuits and overloads is afforded by the 1-ohm feedback resistors in conjunction with current-

limiting resistors in the collector circuits of Q6 and Q9. These resistors limit the instantaneous output current to 4 a. Fuses protect against sustained overloads greater than 3 a.

Because of the low dc voltage and current gains, drift of the output-stage collector currents due to transistor junction temperature changes is held to less than 50 ma. This drift is further reduced by the temperature compensating effect of the diodes used to bias Q6 and Q9. These diodes also form part of a bridge that is used to change the bias in accordance with battery voltage variations so as to maintain constant the output stage no-signal collector currents as the battery voltage changes.

Drift of the output signal point with respect to ground is prevented by overall dc feedback from the output to the base input of Q1. This feedback holds the no-signal output voltage at zero regardless of drift in the intermediate stages. Feedback around this loop is 60 db at low audio frequencies and 80 db at dc, and is in addition to the local feedback around the individual halves of the push-pull output circuit. This feedback is stabilized at high frequencies by means of local feedback loops through small capacitors from the output to the base circuits of Q7 and Q10, and by a network from the collector of Q3 to the input. Because these loops roll off the high frequencies, feedback from output to input at 20 kc is only 18 db.

Relay, K1, is used for two purposes: to provide remote control operation, and to time-sequence the bias and high voltage circuits to prevent a condition during turn-on in which both halves of the output circuit are conducting heavily. K1 is a standard latching relay which has been modified for make-before-break operation. Whenever the bias voltages are off the high voltage is turned off and the signal inputs to transistors Q7 and Q12 are shorted out to prevent the output stage from being driven.

Performance

Transient response is excellent as shown by the square-wave photographs in Fig. 3. These waveforms taken at 50 cps, 500 cps, and 5 kc indicate low phase shift and freedom from high-frequency ringing.

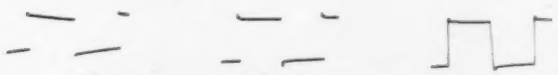

FIG. 3. Power amplifier square wave response. Left: 50 cps; center: 500 cps; right: 5 kc.

The frequency response at 1 milliwatt and the maximum power output at the clipping level are shown in Fig. 4. The response is flat within one db from five cycles to 70 kc. When powered by a regulated supply the maximum output is flat all the way down to dc. Above 15 kc the power output falls off rapidly due to the limitation in the switching time of the output transistors. In this circuit the high-frequency power output is not as great as with transformer drive because the transistors are not as strongly driven to cutoff.

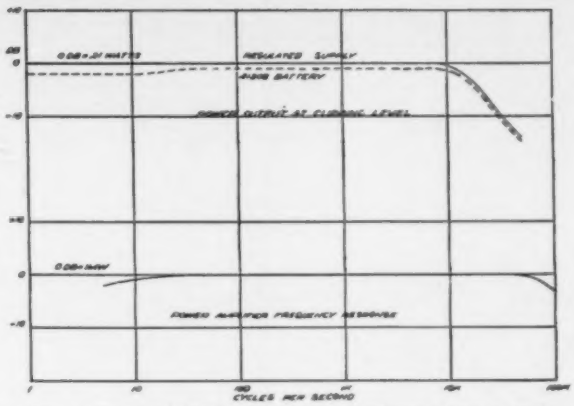

FIG. 4. Power amplifier response and maximum power output.

Distortion at low frequencies is remarkably low, while at high frequencies it is higher but below the point of audibility. Curves of total harmonic distortion at three frequencies are shown in Fig. 5. At 10 cps and full 20-watt output, the total harmonic distortion when using a regulated supply is less than 0.01%. The measuring equipment did not permit measurement at lower levels. At 500 cps the distortion at 20 watts is only 0.014%. Distortion at 10 kc has a fairly level region in the vicinity of 1% and rises rapidly above 10 watts output. However, the principal harmonic content is beyond the range of audibility. In normal reproduction much less power output is required at 10 kc than at low frequencies. Hence, the 10-watt limit for low distortion is of no consequence. The greatest power output is needed at low frequencies where the speaker system is inefficient. This is where the amplifier's performance is outstanding.

When using a battery instead of a regulated supply, the power output is about 1 db lower at high frequencies and 2 db lower below 40 cps. The reason is the power loss in the internal resistance of the battery, which is about 2 ohms. Above 40 cps enough energy is stored in a pair of 4000 microfarad capacitors so that the peak current the battery has to deliver is nearly the same as the average current, a maximum of 660 milliamperes. Below 40 cps the battery has to deliver peak currents of 2 amperes. When reproducing speech and music the average current is usually low and the capacitors are able to hold the battery voltage up to practically its no-load value so that the full 20 watts

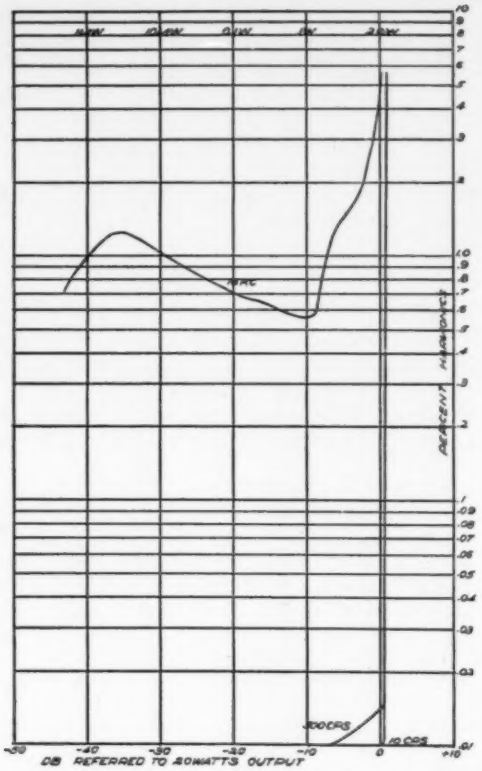

FIG. 5. Power amplifier total harmonic distortion *vs.* power output at 10 cps, 500 cps, and 10 kc.

power output is obtained for millisecond intervals.

The extremely low values of distortion were measured by subtracting the output signal from 30 times the input signal with a resistance-capacitance circuit and reading the difference on an average-reading ac vtvm.

Under overload conditions the amplifier clips cleanly and symmetrically and recovers to its normal low distortion state as soon as the overload is removed. Fig. 6 shows the

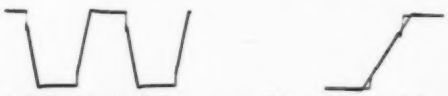

FIG. 6. Left: Overloaded power amplifier output at 1 kc. Right: Transfer characteristic under the same conditions.

output waveform when the input is a 1 kc sine wave approximately 10 db larger than that required for full undistorted output. The squared output is shown at the left. At the right is shown the transfer characteristic of the amplifier obtained by using the input signal for the horizontal sweep.

One peculiarity of this clipping characteristic was noted. As the input signal increases the amplifier output follows faithfully until it limits. Then as the input signal decreases below the overload point, the amplifier output remains at the limiting level longer than it should and finally shoots down rapidly to a point where it starts following the sinusoidal waveform. This point may be considered below the limiting level depending upon the amount of feedback around the amplifier.

At first it was thought that this characteristic indicated a tendency toward feedback instability under overload conditions. Further investigation revealed that it was not any tendency toward instability but apparently a normal overload characteristic for feedback amplifiers in general.

In order to stabilize the feedback at high frequencies it is necessary to roll off the open-loop high-frequency response in a slow manner, usually between 6 and 10 db per octave. This roll-off results in a phase shift or time delay in the error signal, which under overload conditions holds the amplifier in overload for a short time after the input signal has been reduced below the overload point.

The effect is very small at frequencies where the feedback is 30 db or more and is quite pronounced at frequencies where the feedback is 6 to 12 db. In sound reproduction the suddenness of the recovery from overload is very undesirable since it produces high-order harmonics which may be clearly audible.

In this amplifier the recovery time delay has been minimized by using 60 db of feedback at low frequencies and its effect has been reduced to the point where it is unnoticeable when heard over the speaker system designed to accompany this amplifier. The overload waveform at low frequencies shows much less of this effect than the 1 kc waveform in Fig. 6.

TONE CONTROL PREAMPLIFIER

The tone control preamplifier unit is constructed completely with its own batteries in a separate box as shown in Figs. 7 and 8. This system incorporates a 4-channel mixer input for RADIO, PHONO, TAPE, and dynamic MICrophone. The PHONO input has a low-noise preamplifier designed specifically for the ESL Model C1 cartridge. The output amplifier equalizes for the acoustic response of the speaker system. Other controls include VOLUME, BASS, TREBLE, and a MONITOR control for monitoring from tape while recording. The circuit is turned on by a 6-pole, 2-position rotary switch. Push buttons for turning on the power amplifier by remote control are provided.

The connectors for inputs and outputs are all on the side of the unit. There are four inputs, an output to the

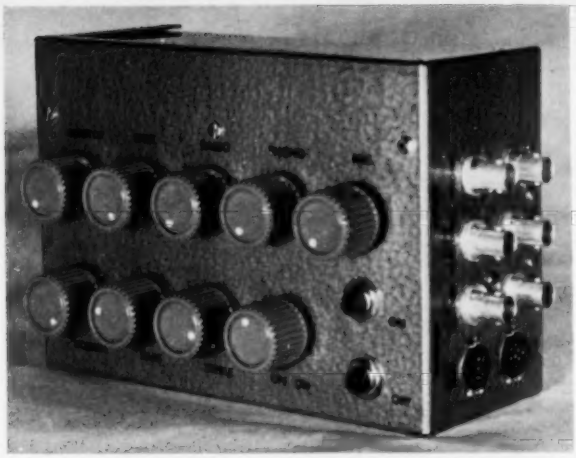

FIG. 7. Self-powered 4-channel mixer and tone control system.

FIG. 8. Inside the tone control preamplifier.

power amplifier, and a tape output jack for recording without using the speaker equalizer. In addition, there is a connector for testing the batteries.

Six 4-volt mercury batteries which last for 1000 hours supply the 2 milliamperes required to operate the circuit. In normal use the batteries need to be replaced only about once a year. Distortion is extremely low and noise is below that of most vacuum tube preamplifiers. Up to 1000 feet of cable can be connected to its output.

Circuit

Referring to the schematic shown in Fig. 9, the tone control system consists of three sections. To eliminate decoupling problems each section is powered by its own positive and negative 4-volt batteries. The first section is a 3-transistor phono pickup preamplifier-equalizer, Q1, Q2, and Q3, using grounded-emitter stages direct-coupled and

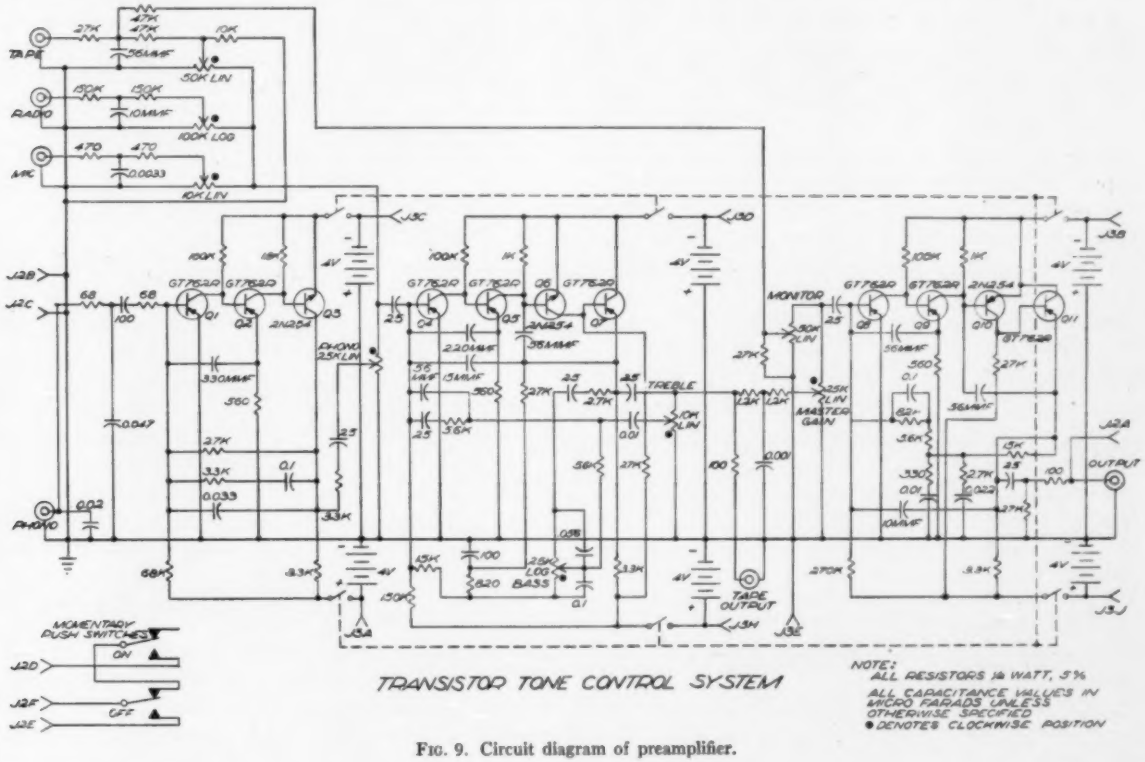

FIG. 9. Circuit diagram of preamplifier.

incorporating overall negative feedback. The input is approximately 2.8 mv peak from the ESL pickup at a maximum recording velocity of 20 cm/sec. Signal and feedback currents are summed at the base of the first transistor. Equalization for the RIAA curve is provided by the feedback network. At 1 kc the feedback is approximately 35 db. Looking into the preamplifier, the pickup sees 140 ohms. Low-noise operation is attained by operating the collector of the first transistor, Q1, at only 0.25 volt and 35 μa.

The phono preamplifier output signal and the other inputs are mixed together at the input of the tone-control amplifier section. Note that each input is followed by a low-pass filter to prevent pickup of local radio stations by rectification at the input stage. This is a feature necessary in an audio system that is required to work in any location.

The tone control amplifier, Q4, Q5, Q6, and Q7 is similar to the phono preamplifier except for the addition of an emitter-follower to increase the gain and feedback. The tone controls are of the feedback type to minimize distortion and noise. Sufficient feedback is provided at dc to stabilize the transistor operating points up to an ambient temperature of 125°F. Maximum output from the tone control system is 1 volt although the nominal level is 0.3 volt. This signal is connected to the TAPE RECORD output jack. The input levels are 3 v rms into 300K at the RADIO input, 1 volt rms into 50K at the TAPE input, and 10 mv rms into 1000 ohms at the MICrophone input. The MICrophone input will accommodate virtually any dynamic microphone having an impedance of 30 ohms or higher.

Following the tone-control amplifier section is a 4-stage output amplifier, Q8, Q9, Q10, and Q11 which provides fixed equalization for the speaker characteristics. All the equalization is provided by means of feedback networks. Feedback around Q11 totals more than 50 db at 1 kc.

Both the signal from the tone control output and the signal from the tape recorder output are mixed into the output amplifier so that it is possible to monitor through the speaker equalizer, either the signal being fed onto the tape or the signal being played back.

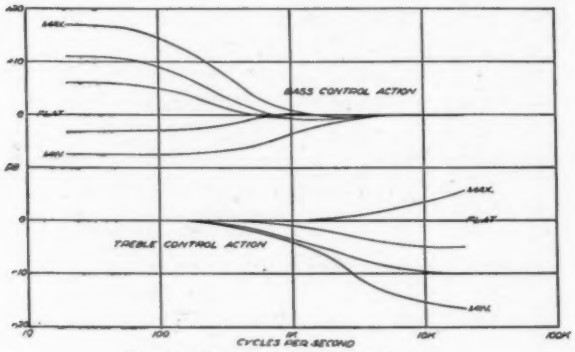

FIG. 10. Bass and treble control action.

Performance

The frequency response at the tape output is shown in Fig. 10. The action of the tone controls shown here was determined by listening tests and the component values were selected by listening tests. There is a flat position off center. Most of the time the controls are not used in their flat positions but more nearly at their center positions where there is some bass boost and treble attenuation. At its extreme positions the bass control boosts 17 db at 20 cps or attenuates 8 db. The treble control boosts 8 db at 20 kc or attenuates 15 db.

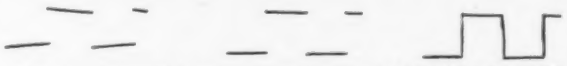

FIG. 11. Preamplifier square wave response at the TAPE RECORD output at 50 cps, 500 cps, and 5 kc.

With the controls at their flat positions the square wave response at the TAPE OUTPUT is excellent as shown in Fig. 11. No ringing at high frequencies occurs because the response is rolled off from 100 kc up. As shown by the lower curve in Fig. 12, the response is flat within 0.1 db from 10 cps to 100 kc.

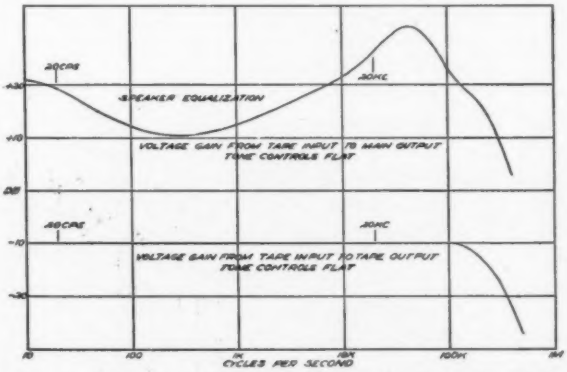

FIG. 12. Response at the output jacks at the flat setting of the tone controls.

The output amplifier has 7 db bass boost at 20 cps with respect to the 1000 cycle level and 14 db treble boost at 20 kc to compensate for the speaker's response. This response is shown by the upper curve in Fig. 12. This is only partial compensation for the averaged response of the speaker system, but was determined best on the basis of listening

tests with an extremely flexible equalizer. Complete compensation at high frequencies seemed to produce too much high frequency output.

Total harmonic distortion is very low. At the TAPE output total harmonic distortion at 1-volt rms output, which is a 10 db overload signal, is less than 0.05% at frequencies up to 10 kc at any control setting. At the main output the distortion is less than 0.05% up to 10 kc when delivering 1 volt rms into a 3.3K load. This level is 8 db above the 0.4 volt needed to drive the amplifier to full output. Under overload conditions and with a 3.3K load, the output waveform is clipped symmetrically.

The response of the phonograph preamplifier is shown in Fig. 13. This curve includes the ESL Model C1 pickup with an RIAA input from an RCA #12-5-49 test record. A peak not shown exists in the region of 18 kc, but an accurate measurement of it was not obtained. Pickup and preamplifier are flat within 1 db from 30 cps to 10 kc.

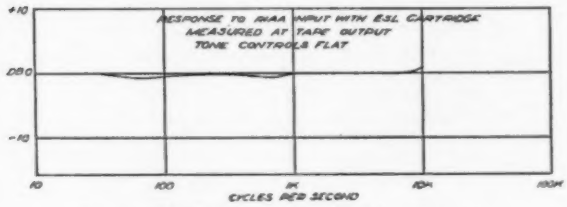

FIG. 13. Phono preamplifier and pickup response.

The noise level of this system is very low. With the volume control turned down noise at the main output is 160 μv. The corresponding noise at the output of the power amplifier is 68 db below 20 watts. Since a considerable portion of this noise lies in the 15 kc to 50 kc region as a result of the speaker equalization, the audible portion is about 75 db below 20 watts. The signal-to-noise ratio at the mixer input with rated input is 73 to 79 db depending upon the mixer control settings. With 10 db above rated input, which this amplifier is designed to handle, the signal-to-noise ratio is 83 to 89 db. Measurements were made with shorted inputs, which in this type of feedback amplifier circuit produce the greatest gain and hence the greatest noise.

Noise at the phono pickup input is remarkably low. Based on the 1000 cycle gain it is only 0.7 μv. Since the 50 cycle gain is 17 db greater, the noise referred to the 50 cycle gain is only 0.1 μv. Assuming a phonograph record to have a maximum instantaneous velocity of 20 cm/sec, this noise level results in a signal-to-noise ratio of 69 db at the phono input. In a system hookup this value is not quite realized because there is some small amount of hum picked up on the external phono lead.

When all gain and tone controls are turned to maximum the maximum noise output from the power amplifier is 0.5 volt which is 27 db below full output. However, with all the controls turned up the gain is far more than would normally be used. The extra gain is needed to take care of the loss when the tone controls are turned to minimum and to provide 20 db extra for speech clipping.

SPEAKER SYSTEM

Two different speaker systems have been constructed; one houses the power amplifier and preamplifier tone control system; the other is used as an auxiliary speaker system. In the combination unit the tone-control preamplifier is made removable so that it can be used either in the cabinet or remotely at the end of a 50-foot cable extendable to 1000 feet. The speaker system with the amplifiers weighs 57 pounds and the auxiliary speaker system weighs 36 pounds. The impedance of each speaker system for matching purposes is considered to be 10 ohms. When the two systems are used together, they are connected in parallel.

The speakers used are a Lansing D-130 15-inch woofer and a Jensen RP 103 horn tweeter. The crossover network consists of a single 10 mf non-polarized electrolytic capacitor in series with the tweeter. Construction of the speaker system is unusual in that the box is entirely live and is deliberately made so rather than being filled with padding in accordance with the latest trend. It was found that the

FIG. 14. Inside the auxiliary speaker system.

live box sounds much smoother and more musical than a dead box even though the response curve has many more peaks. A view of the inside of the auxiliary speaker system is shown in Fig. 14. The tweeter is mounted at the rear of the cabinet instead of at the front.

The compartment for the tweeter performs two functions. It forms a duct for the bass reflex port and it provides a reverberant enclosure for the tweeter. This enclosure is actually like a live listening room in miniature. Its surfaces are convex. Plastic dishes and aluminum jello molds are used to make inexpensive convex reflectors. A perforated baffle mounted at an angle in back of the woofer serves as a non-parallel surface to break up the rectangular wall structures. It also serves as part of a storage compartment for cables.

The response of this speaker system, as might be expected, is full of sharp peaks and valleys. Shown in Fig. 15 is a response curve made in an anechoic chamber with the microphone at 8 feet and 20 degrees to the left of the axis horizontally. Although the response is extremely rough, the speaker sounds remarkably smooth. The result is somewhat similar to that obtained by placing a speaker system in a very live room. While the technique used here is contrary to present-day practice the reason for its use is that it sounds good.

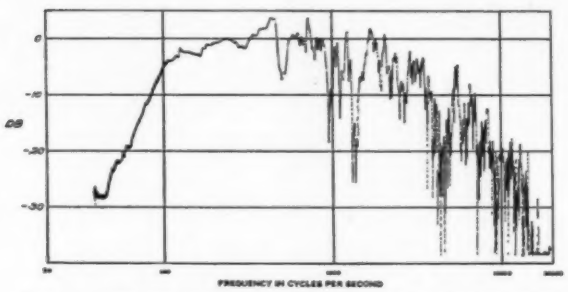

FIG. 15. Response measurement of the auxiliary speaker system, 20 degrees to the left of its axis.

FURTHER WORK

Future work will involve the development of a thermistor network for the power amplifier which will hold the output transistor no-signal collector currents more nearly constant over the temperature range of 0 to 125°F. than the present diode circuit. To improve the high-frequency power output and distortion, new tetrode-type power transistors which have recently become available will be tested in the output stage.

It is hoped that some investigation can be made in regard to improvements in the speaker enclosure and into the reason why the live speaker chamber seems to sound better than a dead one.

ACKNOWLEDGMENT

The author is grateful to Gerard E. McGonagle for his assistance in mechanical work on this system and to the Harvard Acoustics Laboratory for making the loudspeaker measurements.

THE AUTHOR

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A graduate of Harvard University, where he received his Bachelor of Science degree *cum laude* in Physics in 1949, and his Master of Arts degree in Engineering Sciences and Applied Physics in 1950, Mr. Burwen spent the summer of 1949 as a member of Technical Staff at Bell Telephone Laboratories. From 1950 to 1952, Mr. Burwen supervised the development of a wide-band television distribution system at Spencer-Kennedy Laboratories, Inc. He spent the next two years at Krohn-Hite Instrument Company as project engineer on laboratory audio instruments and on its ultra-low distortion power amplifier.

In 1955, he joined National Company, Inc., as research engineer in the Audio and Magnetic Memory Devices Department, where he was responsible for the development of military audio equipment, high fidelity amplifiers, and tone controls. Prior to joining Minneapolis-Honeywell, he served with the Norden-Ketay Corporation, working on transistor military equipment.

Richard Burwen is a member of the Acoustical Society of America, as well as of the AES, and is a senior member of the IRE.

Techniques for Measuring and Evaluating Noise*

J. J. HAMRICK†

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The continually increasing public awareness and concern over noise has required the development of improved techniques and procedures, both to measure and also to evaluate the noise environment created by new products. Modifications of existing instruments and improved operational procedures have been developed for stereo tape recorders and reproducing systems, audio spectrum analyzers, graphic level recorders, and frequency analyzers. Correlation of noise levels in data-processing rooms with laboratory measurements in anechoic and reverberant chambers, together with careful selection and qualification of listening-panel members for annoyance evaluations, have insured that both the loudness and the quality of the noise of a new product will be satisfactory.

INTRODUCTION

WE ARE ALL AWARE of the increasing public attention and concern which is being directed at the noise levels of products ranging from jet aircraft to home refrigerators. The science of noise measurements and the art of noise evaluation are advancing rapidly, and it is worthwhile to review some of the techniques and procedures which can be used to improve the accuracy of the test data, or to simplify the task of securing the data.

Usually concern with noise is due to its possible effects upon the people who are exposed to it. Two of these areas of concern:

1) The necessity to eliminate lasting after-effects to the ear from prolonged exposure to noise, and
2) The requirement that reasonable conversational levels can be used in the work environment,

can be predicted directly from noise analysis test data. The third factor, annoyance, cannot be so predicted, and is discussed in a later section of this paper.

1. INSTRUMENTATION

Portable Instruments

Most of you are familiar with the various makes of portable octave band and narrow band analyzers which are available. In order to make a comparison with the more complete instrumentation to be discussed, let us examine some of the data obtainable with the portable instruments.

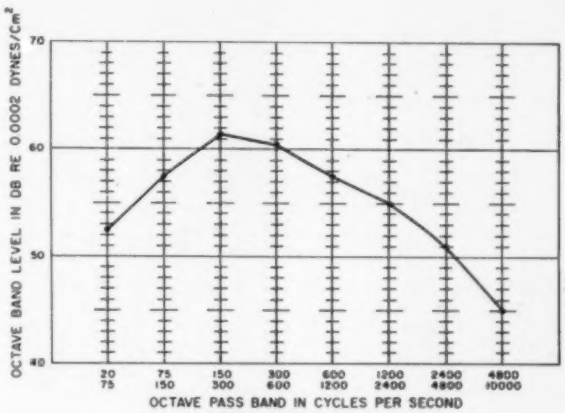

FIG. 1. Octave-band noise analysis.

In Fig. 1 a plot of a typical octave-band analysis of a data-processing machine is shown. This analysis has given no indication of whether there are any pure tones or narrow bands of noise which may be of concern. If we now make an analysis with a narrow-band analyzer, we may secure data similar to that shown in Fig. 2. While the tabulated data is of considerable value, it leaves unanswered such pertinent questions as whether these were the only narrow bands of noise, and what criteria were used to distinguish narrow-band noise from wide-band noise.

Laboratory Instrumentation

The manual operation of frequency analyzers is a very laborious procedure at best, and acoustical engineers prefer to study graphs rather than tables of data. In addi-

* Paper presented at the Ninth Annual Convention of the Audio Engineering Society, New York, October 9, 1957.

† Staff Engineer.

NARROW BAND NOISE ANALYSIS
(2% OF FREQUENCY PASS BAND)

CENTER FREQUENCY	SOUND PRESSURE LEVEL, DECIBELS	SOUND PRESSURE LEVEL OF ADJACENT SPECTRUM, DECIBELS
81	57	45
122	57	47
163	56	45
203	53	45
245	54	45

FIG. 2. Narrow-band noise analysis.

tion, many pure tones vary in intensity with time, and it is difficult to visually estimate the average sound pressure level from a very slowly swinging pointer. Fig. 3 shows the modifications made to a sound analyzer. A mechanical drive is brought out which couples this instrument to a graphic level recorder, so that an intensity *vs.* frequency plot may be made.

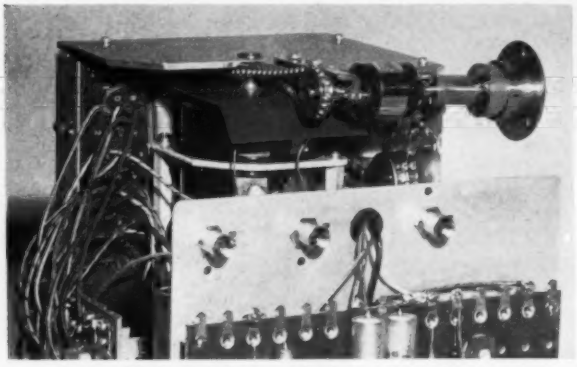

FIG. 3. Mechanical drive details for sound analyzer.

Fig. 4 shows an example of such an analysis. The pure tones stand out very conspicuously above the general spectrum. Note that as a sweep is made past a pure tone, the response curve of the filter in the frequency analyzer is traced out.

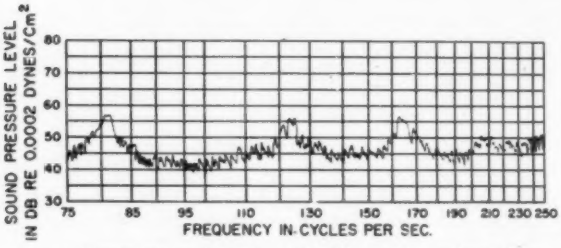

FIG. 4. Frequency *vs.* intensity plot with a 2% pass-band filter.

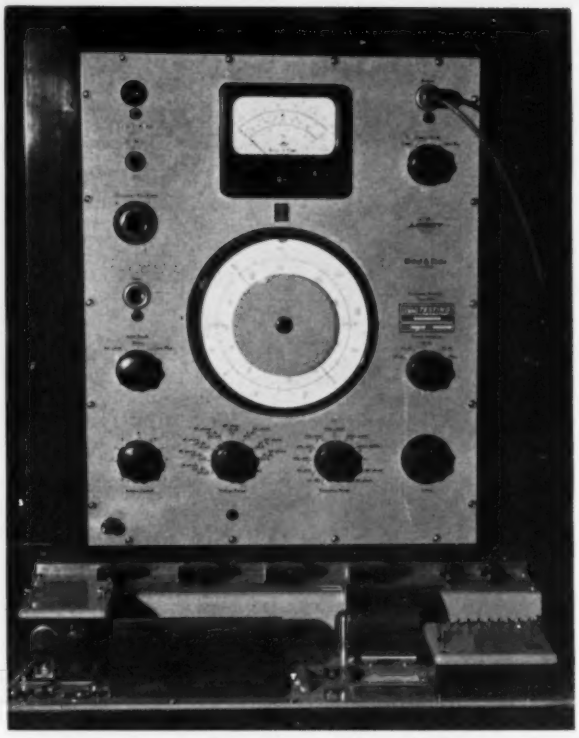

FIG. 5. Frequency analyzer (above) with graphic level recorder.

Fig. 5 shows a different frequency analyzer (Bruel & Kjaer) which has been mounted directly in a cabinet with a graphic level recorder. The details of the mechanical coupling system which has been designed to drive the frequency analyzer appear in the lower left corner of Fig. 6. A slip clutch is incorporated to prevent any damage to the mechanism, and a micro-switch prevents overtravel at the end of the sweep.

Both of these instrument modifications have proved to be convenient and reliable, and both have the advantage that the dial of the instrument is not obscured, nor is there any physical handicap to quick and accurate operation of the instruments.

Both octave analyses and narrow-band analyses have been discussed. A third-octave analysis combines some of the rapidity of an octave analysis with some of the additional information gained in a narrow band analysis. Such an instrument is shown in Fig. 7, and Fig. 8 illustrates a plot of the information obtained with this instrument.

In the third-octave analysis of a data-processing machine shown in Fig. 8, the pure tones at 82 cps and 164 cps stand out very clearly; however, in the full octave analysis of

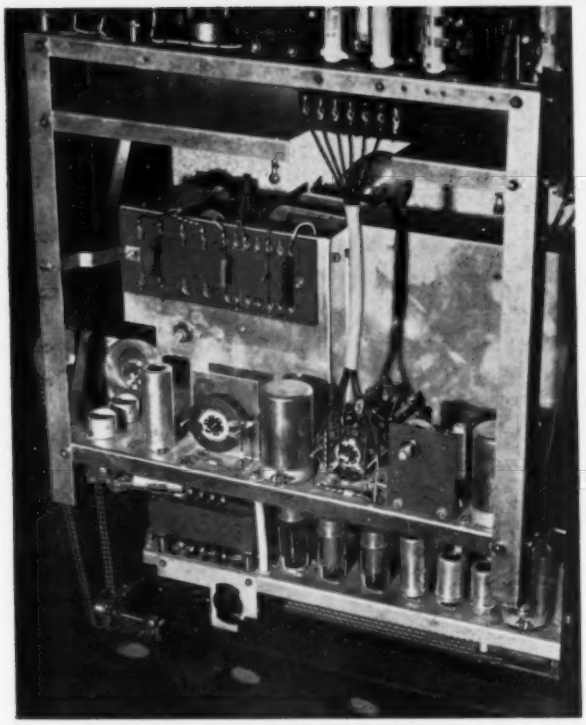

FIG. 6. Details of mechanical coupling between the two instruments.

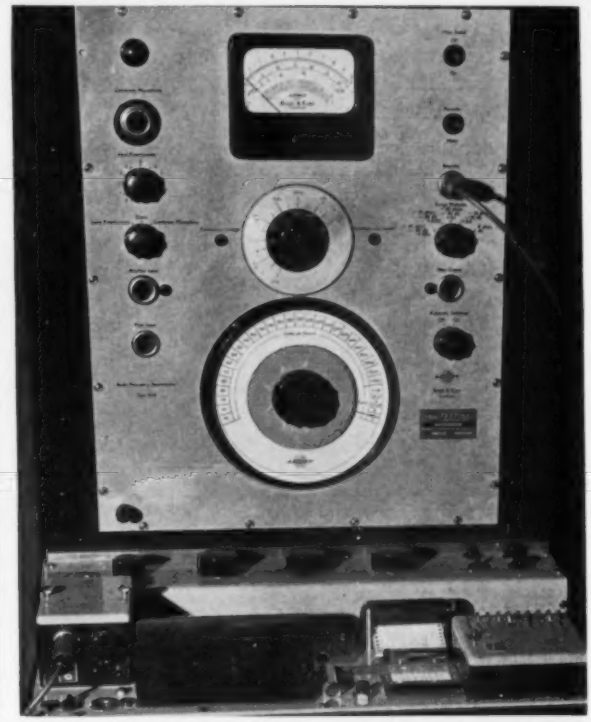

FIG. 7. Third-octave audio spectrum analyzer with graphic level recorder (below).

the same data-processing machine shown in Fig. 1, the pure tones are not apparent.

A modification which is now under construction for this analyzer adds an input panel with 27 step attenuators, each having a range of ± 10 db. Each of these attenuators is connected to a 27-position switch coupled to the analyzer, so that as the analyzer switches from one third-octave to the next, the corresponding attenuator is switched into the circuit. The three curves of Fig. 9 illustrate the use that is made of these attenuators.

The top curve is the calibration of a microphone often used in noise analysis work; the center curve is the calibration of a third-octave analyzer *plus* its graphic level recorder; the bottom plot, derived from the preceding two, shows the corrections which must be made to any data taken with this system. By incorporating this last data into the 27 attenuators on the input panel, the analysis becomes correct as indicated, and no further data handling is necessary to correct the errors due to instrumentation.

In Fig. 7, a graphic level recorder was shown as an integral part of the third-octave analyzer. With such an instrument, plots of intensities *vs.* third-octave sound pressure levels may be made automatically and very rapidly. However, great care must be used in interpretation of the graphs, as the meters used for sound instruments are average-responding meters calibrated in rms values, whereas the graphic level recorders generally used for sound analysis are quasi-peak instruments. Thus, for a complex noise, the values obtained from a graphic level recorder will not

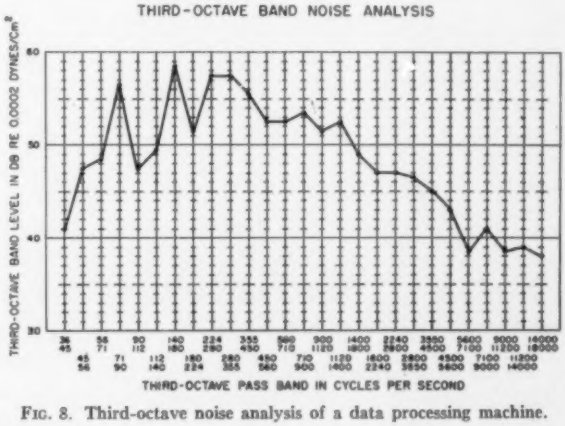

FIG. 8. Third-octave noise analysis of a data processing machine.

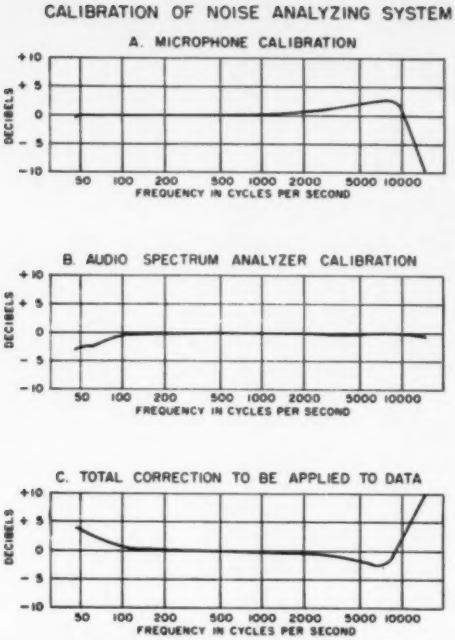

FIG. 9. Calibration curves for noise analyzing system.

be the same as the values obtained by reading the meter, and the differences will be dependent upon the technique used for calibrating the recorder. A plot of the errors of two makes of graphic level recorders *vs.* the quasi-peak to rms ratio of the noise being observed is presented in Fig. 10.

Up to a peak-to-rms ratio of 5, the graphic level recorders show an error of about one decibel. For noise with a peak-to-rms ratio in the neighborhood of 8 to 13, an error of 3 to 5 db may be expected in the observed values. Techniques are available to minimize these errors, but none will bring them down to what we can call negligible. As practically all psychoacoustical data and criteria have been established from meter readings, it is usually necessary to read the meters for a complex noise, unless errors of the magnitude shown can be tolerated. For pure tone analyses, the graphic level recorder can be calibrated on a pure tone, and since the peak-to-rms ratio of pure tones is constant, the graphic level recorder will indicate true levels for these pure tones.

We have had designed, and presently have under construction, a modification to our Bruel and Kjaer graphic level recorder which will make it a true-average level recorder, so that it will display wide band noise and pure tones in their proper relationship.

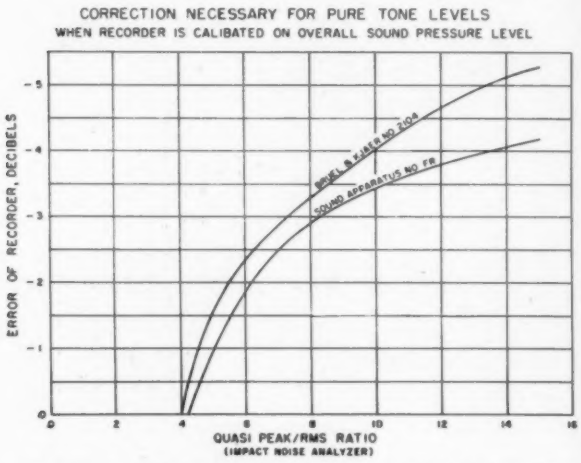

FIG. 10. Errors in pure tone intensities for graphic level recorders calibrated on overall noise level.

Test Chambers

Another item of major importance is the enclosure used for testing. Fig. 11 is a view of an anechoic chamber which has very little reflected sound down to perhaps 150 cps, with an attenuation from outside to inside of about 60 db.

FIG. 11. Anechoic test chamber.

Analyses of relatively quiet machines can be made inside this room with no disturbance from the rather noisy conditions which exist outside. It is of interest to note that this room has a rather hard floor of composition tile. The reason for this is that most data-processing installations have composition tile floors, and the noise from machines is reflected back up by the floors. In this chamber such conditions have been duplicated to give the effect of a data-processing room with infinitely spaced walls.

It is tedious and time consuming to determine the average acoustic power output of machines in anechoic chambers because the microphone must be located at many points of a hemispherical surface. To avoid this laborious procedure, the reverberation chamber shown in Fig. 12 is used.

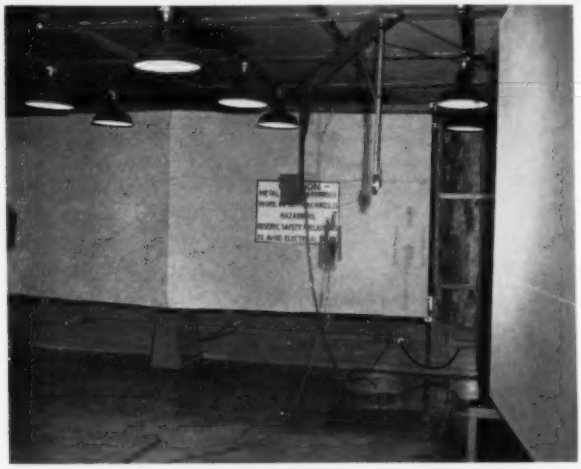

FIG. 12. Reverberant test chamber.

Note the movable vanes which are used to eliminate standing waves. The determination of the average acoustic power output of a machine or a system permits the computation of the noise level which it will create in a given environment.

2. PSYCHOACOUSTICAL EVALUATIONS

As an example to show why listening panel evaluations are necessary to judge annoyance, I would like to describe an experiment which was conducted. Two machines were picked as noise sources and located near each other on one side of a large data-processing room. One machine had considerable high-frequency output and a quite high speech interference level; the other machine, which was somewhat slower, had a speech interference level about 10 db lower than the faster one. The faster machine made a rather "whirring" sound, whereas the slower one made a "thumping" noise. The listening panel was located on the other side of the large room.

By all of the "rules of the road" that are quoted on annoyance, such as (1) people must be able to communicate or they are annoyed, (2) high frequencies are more annoying than low frequencies, (3) the spectrum should have a certain contour to sound "normal," the higher speed machine should have been judged as more annoying. However, to the listening panel, the "whirr" of this machine blended into the general room noise, but the "thump" of the lower speed machine carried right through the ambient level and was judged to be more annoying.

Listening Panel Subject Selection

There are many textbooks which have been written on the subject of member selection for psychological evaluations. In our psychoacoustical evaluations, we have secured good results by following three rules:

(1) The subjects must be reasonably intelligent and observant people of both sexes and possess a general familiarity with data-processing equipment.

(2) They must have had experience with the likes, dislikes, and tolerance levels of data-processing customers.

(3) They must be able to hear all of the components of the noise they are going to be asked to judge.

In selecting proposed members for a listening panel, item 1 may be evaluated from a brief conversation. Item 2 is verified from the person's previous employment history. Item 3 involves securing audiograms with an audiometer such as shown in Fig. 13.

FIG. 13. Modified audiometer.

Audiometers are ordinarily designed to cover the range of speech frequencies; most of them start at 125 cps and

go up to about 8 kc. Inasmuch as high-speed components exist in data-processing machines which produce noise above 8 kc, it was necessary that the audiometer cover more than this band of frequencies. We had the manufacturer of this instrument omit two of the frequencies of lesser interest, and substitute frequencies of 12 kc and 14 kc. Research was necessary to establish the levels of these frequencies, as very little high frequency data exists in the literature.

After audiograms have been secured for both ears of an individual, the hearing for these two ears is combined using the procedure recommended by the American Medical Association,‡ in which the better ear is given seven times the importance of the poorer ear. We consider a range of ± 10 db about the zero reference level to be normal hearing to qualify people for listening panels. I might point out that the reason that we are interested in this extended range of hearing is that generally young people do have quite good high-frequency hearing, and our customers' operators are relatively young people.

At this point, a fair question would be: "Why go to all of this trouble? Why not just interview actual or potential customers for their opinions?" On questions of fact, such as speed of operation, carefully conducted customer interviews may be valid; on questions of opinion and judgment, they are much more uncertain. Mr. X's tolerance level for noise was affected Wednesday morning because he had a cold, because his toast was burnt at breakfast, and because he got caught in a traffic jam on his way to work. Yet neither the interviewer nor the subject can weigh these factors in an interview. There is another hazard in the fact that, generally speaking, as soon as a person is asked whether or not he is satisfied, immediately he realizes that he is not.

Psychoacoustical Test Procedure

In an evaluation such as that of a large data-processing system, it is desirable to take the listening panel right into the room in which the system is located. They should conduct both face-to-face and telephone conversations, and the telephone circuit should go through a telephone exchange, not just a local switchboard. In both cases, the conversations should consist of transmitting previously unfamiliar information, so that the degree of intelligibility can be verified. After the subjects have had an opportunity to decide in their minds how they feel about the noise level of this equipment, they are asked to fill out a simple questionnaire in which they rate the noise level. One end of the scale ranks the noise intolerably loud, and the other end of the scale ranks the noise as quieter than is desirable. It should be pointed out what is meant by a noise level which is quieter than is desirable. At such a level, conversations between other people in a room intrude upon you and become annoying. Most people are much happier if there is an adequate background level: one which is rather indistinguishable but serves to mask individual noises that would otherwise be distracting.

Such a study will give quite a range of replies, probably all the way from that of a young woman with above average hearing who says, "This noise level does not bother me at all—I'm perfectly happy to spend my working lifetime in this environment," to that of an older man with below-average hearing who may say, "I would quit the company before I would be exposed to such a noise level for any length of time."

For this reason, it is always necessary to make a statistical study of panel replies to questionnaires. In this particular instance, a statistical study enabled the prediction that if this device were produced and sold without further noise reduction, it would be an acceptable product when installed in a room with other data-processing equipment. However, if the system were to be used in an individual room in

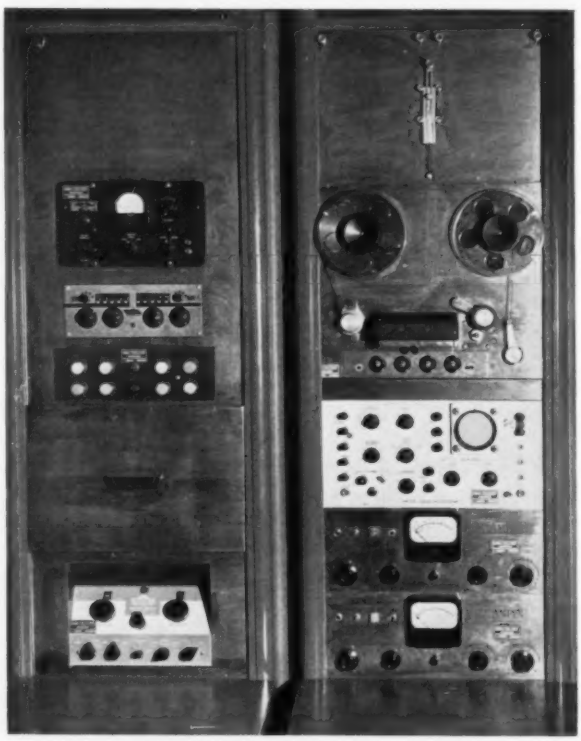

FIG. 14. Binaural tape recorder and playback system.

‡ H. A. Carter, *J. Am. Med. Assn.*, **133**, 396 (1947). [Ed.]

which it would be the chief noise source, noise reduction must be incorporated.

In this evaluation, absolute judgments were made. This is not always desirable, as it is difficult for one to judge how annoyed he is, just as it is difficult for him to establish the absolute level for a headache. These uncertainties are avoided by asking the listening panels to make only comparative judgments—such as "B" is better than "A," or "B" is better than "A" but worse than "C." In this way, a rank order of annoyance can be established, and absolute levels may be disregarded for the moment.

For these comparisons, we prefer to present the noises under evaluation through a binaural tape recorder and playback system. In Fig. 14 is shown the twin-track tape recorder used for these tests.

Above the playback mechanism is a tape loop system, and below the playback mechanism is an oscilloscope used to monitor the noise levels, due to the impact quality of many noises which are recorded. The oscilloscope is used as follows:

> With the tape recorder operating at 15 ips, a sine wave input is adjusted to provide a –10 db indication on the VU meter, and the oscilloscope gain adjusted to display the sine wave at full deflection. The oscilloscope gain is not changed from this setting. The gain control of the tape recorder is adjusted to give the noise the same full scale deflection on the oscilloscope as the calibration sine wave. With this procedure all noise recordings are made with the highest peaks at –7 db *re* the VU meter of the tape recorder. Working at these low levels, the following frequency response is obtained from this tape recorder, (Fig. 15).

Rank Order System of Annoyance

From the binaural comparisons previously discussed, we can go further than merely to judge that "B" is better than "A" but worse than "C." If many products are under consideration, sufficient comparisons can be made until all of the products have been judged and ranked in a list from the least annoying at the top of the list to the most annoying at the bottom. This list should then be correlated with known customer reactions to the various noises, and absolute levels thereby established. With such a list, a few comparison tests on a new product will disclose where it ranks with the other products, and predictions can be made as to its probable acceptability to the customer.

FIG. 16. Noise analysis instrument area of IBM testing laboratory.

This, in turn, makes clear whether further noise reduction is required.

In conclusion, Fig. 16 illustrates the instrument area which is used for the noise analyses which have been discussed.

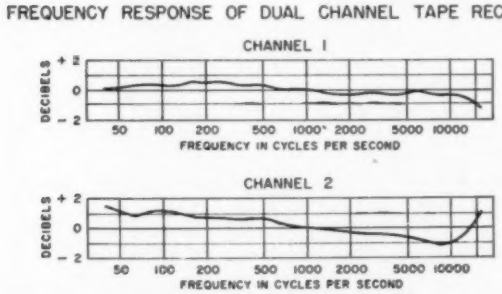

FIG. 15

THE AUTHOR

Mr. J. J. Hamrick is a staff engineer with the International Business Machines Corporation at Endicott, New York.

Mr. Hamrick attended Marshall College in Huntington, West Virginia, from 1935 through 1937. In addition, he has specialized at Columbia University and Massachusetts Institute of Technology in the fields of instrumentation, acoustics, and psychology of man-machine systems. He is the author of "The Rapid Determination of Paper Moisture Contents," published in the ASTM Bulletin, for December 1955.

In 1937, he joined the Chesapeake & Ohio Railway company, Huntington, West Virginia, where he worked for several years in the Physical Testing Laboratory. He became associated with I.B.M. in 1952. Since 1954, he has been in charge of research and development of testing techniques in the fields of acoustics and psychology of man-machine systems.

Mr. Hamrick is a member of the Audio Engineering Society, Acoustical Society of America, American Institute of Electrical Engineers, and the Institute of Environmental Engineers.

Variable-Speed Scanning of Recorded Magnetic Tapes*

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A device for critical examination of recorded data on moving or stationary magnetic tapes by means of variable-speed rotating magnetic reproduce-head assemblies is described. Several types of interchangeable assemblies, both single- and dual-track, are discussed, together with certain operative phenomena peculiar to each.

Problems arising from the use of variable-speed scanning as a means of analyzing recorded analog data are illustrated.

The effect of rotating-head design on wow and flutter is described in detail, as well as the ability of current magnetic tapes to withstand physically high-speed scanning for prolonged periods of time.

Although the system was designed primarily as a tool to aid in the development of data-recording devices relative to the field of sonar, its application to other fields of scientific research is discussed.

INTRODUCTION

THE ABILITY to collect and survey volumes of data recorded in many forms is one of the fundamental requirements of an establishment such as the Underwater Sound Laboratory, which is concerned with the study of basic physical concepts. Analysis of these data provides a very useful tool in directing thinking and action in the development of electronic systems. The techniques involved in analyzing recorded data vary, depending upon the type of information to be extracted. In some instances, unique procedures may demand the application of equally singular instrumentation which is not commercially available and which must therefore be designed and developed. It is the purpose of this paper to discuss such a device.

DESCRIPTION OF THE ROHAS

Designated "ROHAS" (for ROtating Head ASsembly), this device consists of (1) a magnetic-tape transport capable of pulling ¼" tapes at linear velocities in doubling increments from 1.875 to 60 ips and (2) a variable-speed, rotating reproduce-head assembly. The complete unit as seen from the front is illustrated in Fig. 1. At the top is the rotating reproduce-head speed control; next is the tape transport and the rotating head; the tape-spooling panel is third from the top. Below this are the record and reproduce amplifiers. The gain of the latter falls off at a rate commensurate with the increase in scanning-head output, which is proportional to the scan speed.

Interchangeable, rotating, magnetic reproduce-head assemblies, which may be either single or multi-track, have been designed and constructed as integral parts of the tape transport. These assemblies are driven independently of the tape motion at scan rates which are continuously variable from 0 to 200 ips. Each scan-head assembly consists of two electrically matched magnetic reproduce heads located diametrically opposite each other. These heads are accurately aligned and positioned by means of precise electrical and mechanical measurements. They are then locked in position to insure that the relative displacement remains unchanged. The heads are connected electrically in series, and the signal energy is taken from the assembly through rings and wiping contacts.

Attached to the scan-assembly shaft is a relatively large flywheel which is friction driven through a 2-to-1 speed reduction by means of a variable-speed dc motor. The flywheel and motor may be seen in Fig. 2, which also shows the toothed rubber belt tape-capstan drive. Originally, direct drive was employed, but instability of the dc motor at slow speeds created wow which exceeded 2%. As will be shown, this figure has been reduced by a considerable factor. At-

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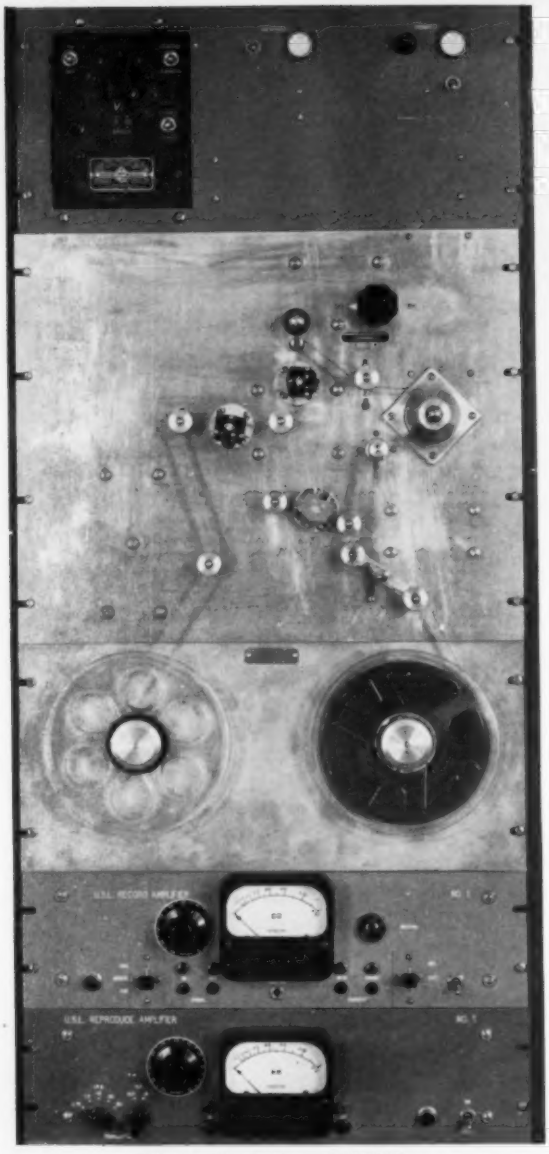

FIG. 1. Front view of ROHAS.

tached to the flywheel in positions corresponding to the displacement of the magnetic heads are two small particles of slightly magnetized material. As the flywheel rotates, these particles pass an impulse counter, the electrical output of which is amplified and used to synchronize the sweep of an oscilloscope. Once the signal pattern generated by the scan assembly has been locked on the oscilloscope screen, it will remain self-locking throughout the scanning-speed range.

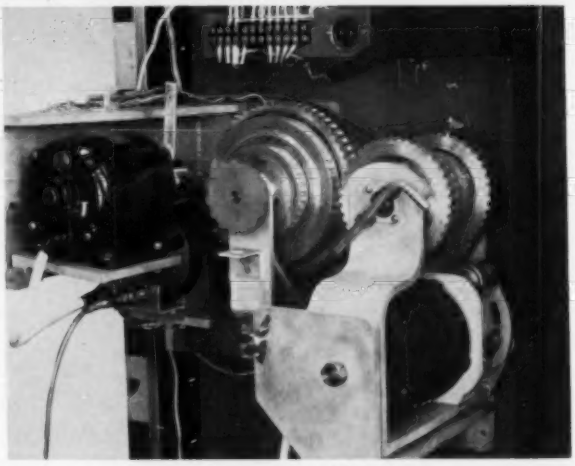

FIG. 2. Rear view of ROHAS.

APPLICATIONS

By means of this system, it is possible to record on the tape and then, while it is in motion, to scan the tape at various speeds. The ROHAS has found much greater application, however, in scanning stationary tapes. The tape is advanced until a desirable section of recorded material is located; it is then stopped and the scan assembly is operated. This process permits examination of a single pulse by repeating it over and over at such a rate that a very-narrow-band spectrum analysis may be performed, as shown in Fig. 3. In Fig. 3A is seen a graphic presentation of a 1/15-second-duration pulse. In order to analyze this pulse and examine its component parts, it was necessary to record it and then reproduce it in such a fashion as to accelerate repetition to a rate which would permit analysis equipment to see essentially a steady-state signal. The lower trace shows the spectrum analysis obtained as a result of scanning this pulse at a rate 120 times the original recorded speed.

As a result of proper positioning of the tape, the various sections of a pulse may be examined in detail. Fig. 4 depicts

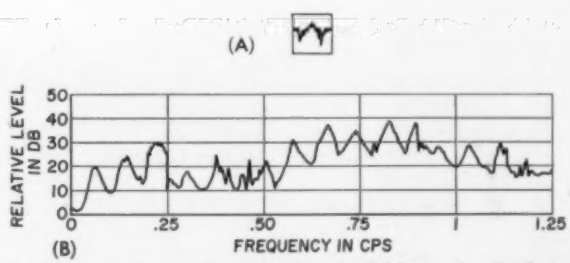

FIG. 3. Spectrum analysis of pulse. A—Original pulse. B—Spectrum analysis of pulse obtained by scanning pulse at 120 times the recording speed.

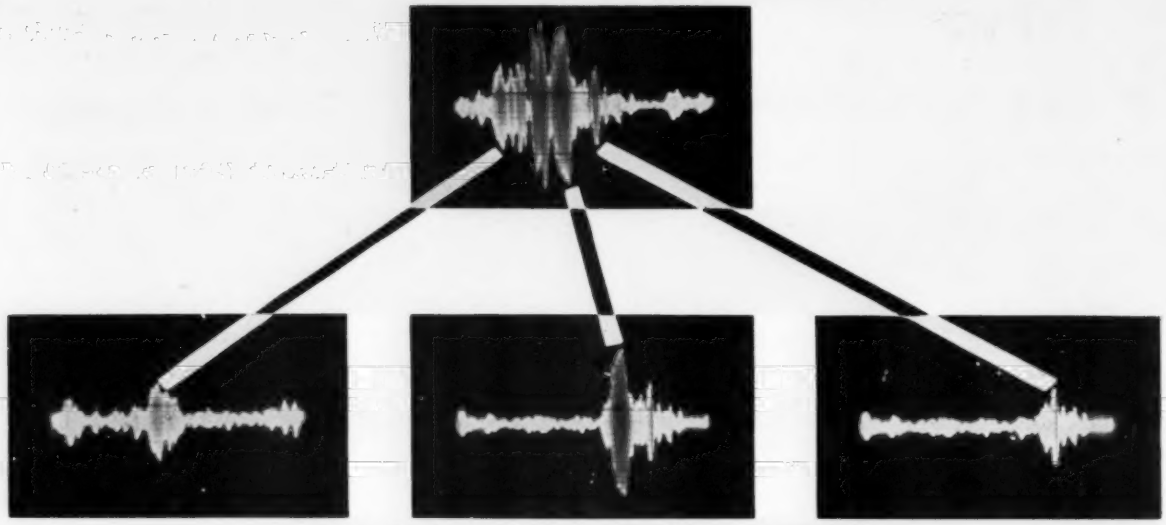

FIG. 4. Examination of echo components by means of ROHAS.

a sonar echo from a submarine and illustrates the manner in which portions of this pulse may be examined individually by means of a scan assembly. In Fig. 5A may be seen the same echo reproduced in sequence by the scan assembly at a velocity five times that of the recording speed. When one pulse in this train of pulses is enlarged as shown in Fig. 5B, it can be seen that the original pulse structure has been retained. Broad-band analog data may be processed in the same manner.

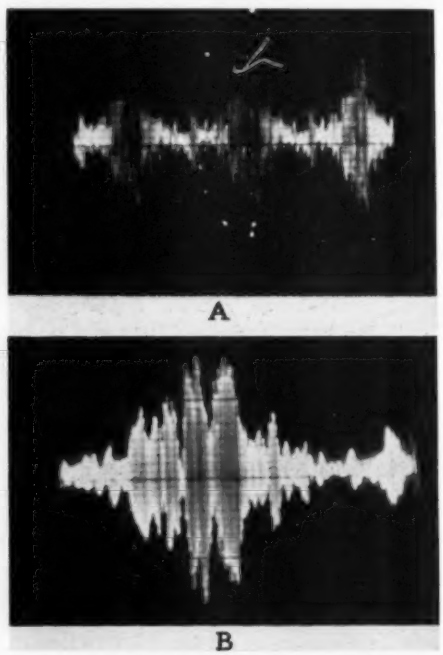

FIG. 5. Example of sequential scanning by ROHAS. A—Echo scanned in sequence at 5 times the recording speed. B—Enlargement of one pulse in the sequential train.

Frequency multiplication and division are two products of the variable-speed scanning process which are utilized in several ways. By reproducing infrasonic signals at velocities greater than the recording velocity it is possible to multiply these data into bandwidths over which high-speed analyzers may function, provided proper compensation for the related frequency multiplication is made. Similarly, it is possible to record ultrasonic signals and to reproduce this data at reduced speeds which convert the bandwidth to a range convenient for study. That bats and certain fish are guided by echoes, received when pulses of high-frequency energy which they emit strike objects in their path, has been proved by this method.

DESCRIPTIONS OF SCAN ASSEMBLIES

Four different scan-head assemblies have been designed and constructed for the ROHAS system. The unit shown in Fig. 6, with its outer cover removed, contains two high-impedance heads which have 0.0005-inch front gaps. When this assembly is used, the tape is in contact with exactly one-half of the circumference of the assembly; the tape is supported only by its edges. Therefore, the recorded surface of the tape is subjected only to the wiping action of the heads. This type of support is advantageous as far as tape wear is concerned. Since each head must push

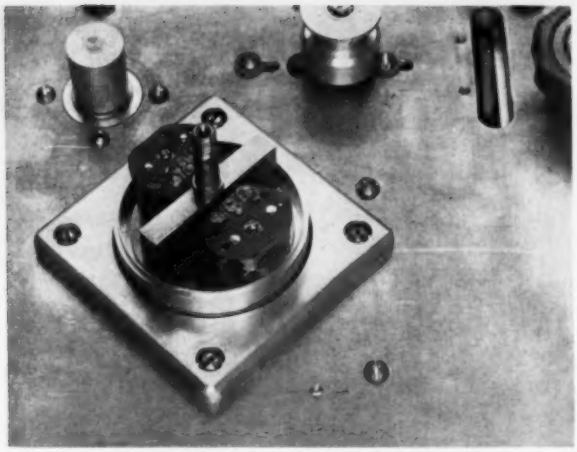

FIG. 6. Open scan-head assembly, with bell cap removed.

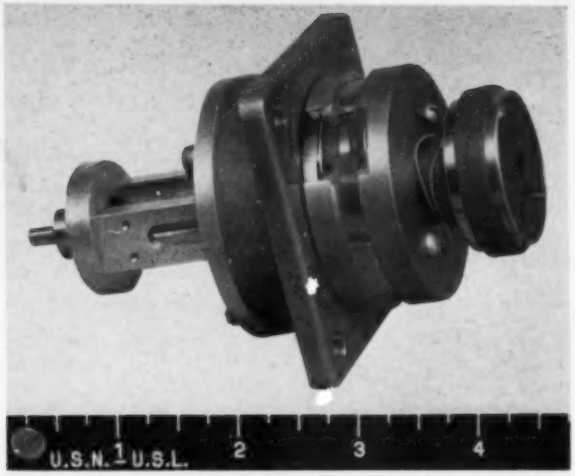

FIG. 8. Experimental, solid, single-track, magnetic scan head.

emphatically against the surface of the tape as it engages and leaves the latter during rotation, each pole piece of each head is adjusted to protrude 0.005 inch beyond the tape-support surface. As a result, a pronounced transient is generated. This effect is shown in Fig. 7. The upper portion of this figure shows the results of analyzing a band of energy as it is scanned at the rate at which it was originally recorded on the tape. The lower part shows the analysis of the same energy scanned at 10 times the normal velocity. Note the pronounced transient and related harmonics which are apparent as a result of the individual magnetic heads whipping the tape. This transient appears at the rate at which each individual head engages the tape. If the scanning head consists of two magnetic reproduce heads, the transient will appear as two pulses per revolution of the assembly.

A second high-impedance rotating-head assembly is illustrated in Fig. 8. As may be seen, the tape is now supported across its full width. The heads themselves have been imbedded in plastic. Other than this plastic, the tape is in contact with only polished brass surfaces. Since the tape is always firmly in contact with the circumference, it is not necessary to have the pole pieces themselves protrude more than 0.0005 inch beyond the adjacent surface; hence the scan transient is greatly reduced. Friction between tape and head assembly is greatly increased, however.

It is sometimes necessary to scan continuously a selected portion of recorded tape at high speed for 15 minutes or more when fine-grain spectrum data are being examined. During this period, the oxide coating on some tapes becomes

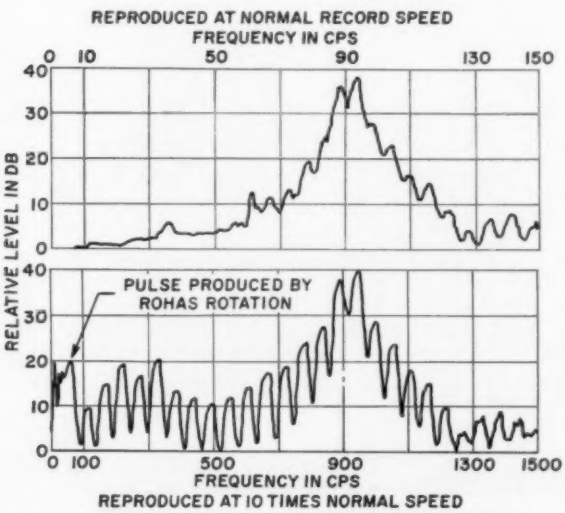
REPRODUCED AT NORMAL RECORD SPEED
FREQUENCY IN CPS
0 10 50 90 130 150
RELATIVE LEVEL IN DB
40 30 20 10 0
PULSE PRODUCED BY ROHAS ROTATION
0 100 500 900 1300 1500
FREQUENCY IN CPS
REPRODUCED AT 10 TIMES NORMAL SPEED

FIG. 7. Effect of whipping action of rotating-head assembly.

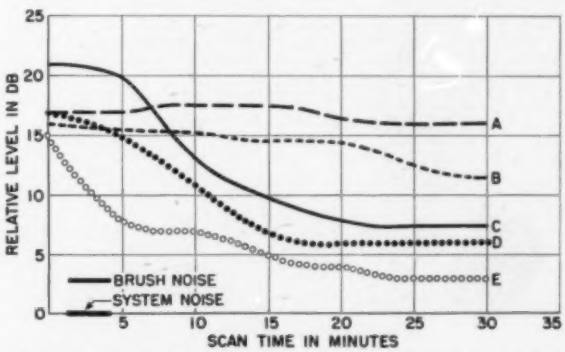

FIG. 9. Deterioration of 1000-cps signal on various tape samples when scanned with solid head at 200 ips.

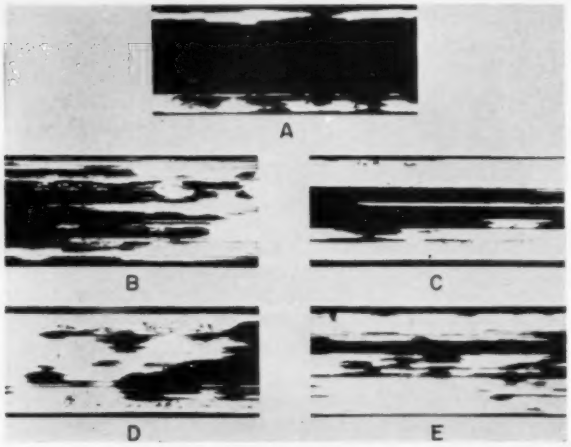

FIG. 10. Deterioration of oxide coating on various tape samples resulting from high-speed scanning with solid head.

heated and deteriorates rather rapidly; this deterioration is accompanied by a comparable loss of signal energy. The reduction in signal level during 30 minutes of scanning five samples of tape at 200 ips with this solid head is shown graphically in Fig. 9. Fig. 10 illustrates the condition of these samples at the conclusion of this test. In contrast, when the open type of head assembly was employed, tapes were scanned for over three hours with little loss of energy and with only a polished effect apparent on the oxide surface.

Comparative wow and flutter measurements were made with both the solid and open type of scan assembly operating at linear velocities of up to 200 ips. The results of these tests may be seen in Fig. 11. Flutter components introduced in a 14.5-kc signal were measured in a band 5000 cps wide. It can be seen from this illustration that the

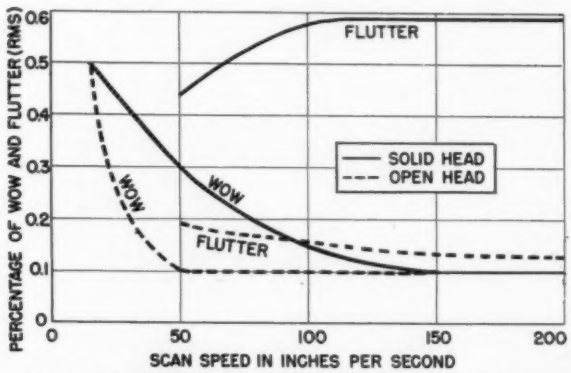

FIG. 11. Wow and flutter of solid and open scan heads as measured in 5000-cps bandwidth.

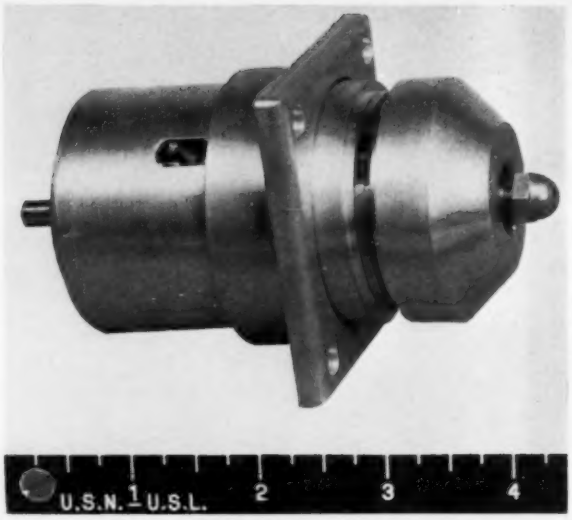

FIG. 12. Single-track magnetic scan head.

increased friction introduced by the solid scan-head structure has a marked effect on the flutter content and affects, to a lesser extent, the percentage of wow.

A third type of rotating scan-head assembly is shown in Fig. 12. This unit is similar to the solid type of assembly just discussed, except for the fact that the individual magnetic heads contain 0.00025-inch gaps.

Figure 13 illustrates a dual-track scan-head assembly. It is possible to displace the pair of heads of one track with respect to the fixed heads of the other track for correlation studies. At present, this head must be indexed manually

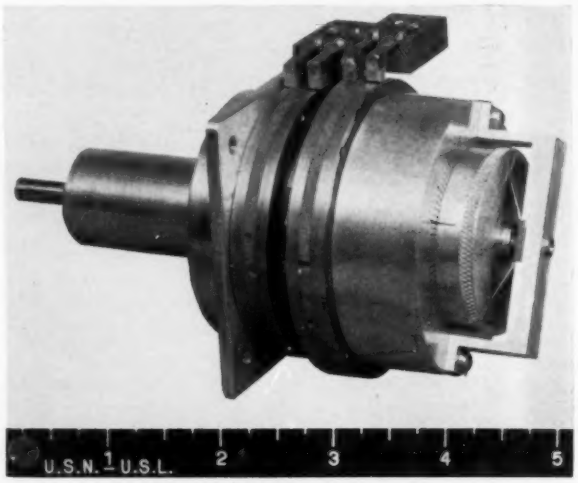

FIG. 13. Dual-track magnetic scan head.

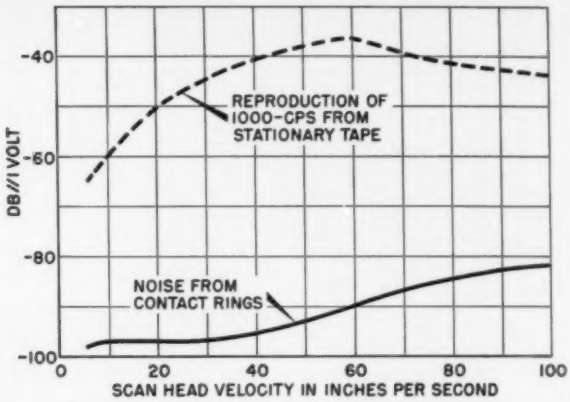

FIG. 14. Scan head open-circuit signal-to-noise ratio.

by means of a 20-to-1 epicyclic-gear reduction system. The maximum delay time available ranges from 15 msec at a scan speed of 200 ips to 1.6 seconds at 1.875 ips. In order to insure proper dynamic balance, a double gear train was installed, where normally only one is required. With slight modification, indexing between tracks can be made automatic for autocorrelation work.

One of the principal items of concern in work with rotating scan-head assemblies is the noise introduced by the signal take-off contacts. Wiper contacts are used on all the scan-head assemblies which have been described. In Fig. 14 are compared the noise level created by the contact rings and the level derived from scanning, at speeds of up to 100 ips, a stationary portion of tape on which a 1000-cps sine wave was originally recorded at 15 ips. These measurements were made directly at the output terminals of the head assembly and reflect no equalization. It is hoped to improve this signal-to-noise ratio by incorporating a transistorized preamplifier in the scan-head assembly itself.

Early in the development of the ROHAS system, it was found that it was necessary to readjust the wrap of the tape about the scan assembly whenever scan assemblies were interchanged. This is essential, since one head must leave the tape at the instant the other engages it. A micrometrically adjustable idler was provided to control the angle at which the tape enters the scan head. By observing a signal on the oscilloscope as reproduced by the head it is possible to adjust for a precise wrap of slightly less than 180°. A wrap greater than this is indicated by a peak superimposed on a signal envelope at intervals equal to the scan rate. Insufficient wrap is indicated by a notch in the envelope at the same rate. This adjustment becomes more critical at short wavelengths, and phase distortion is introduced if each head does not engage the tape in identical phase relationship to any sine-wave signal recorded on the tape. For random analog data, this effect is reduced considerably.

OPERATING PHENOMENA

While the performance of the ROHAS system at high scan speeds was first being evaluated, several interesting phenomena were observed. Certain tonal components ob-

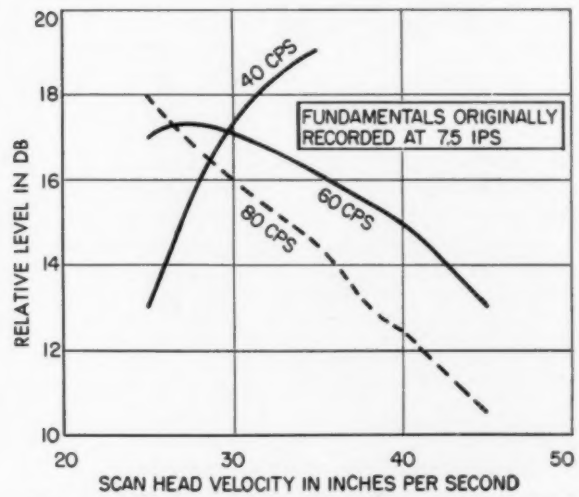

FIG. 15. Variation of second harmonics of 40-, 60-, and 80-cps signals as a function of scan speed.

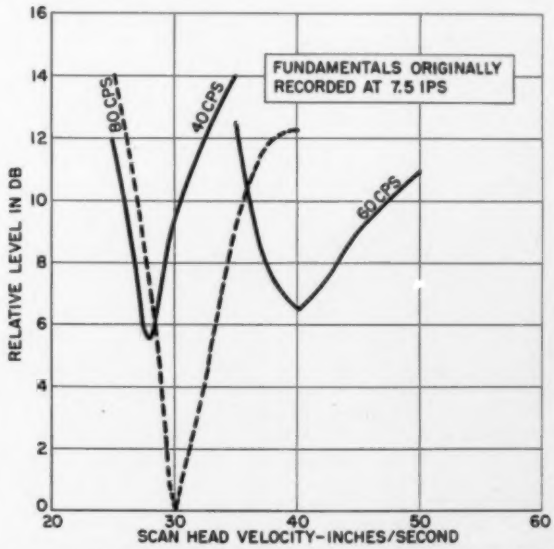

FIG. 16. Variation of third harmonics of 40-, 60-, and 80-cps signals as a function of scan speed.

served during spectrum analysis of sinusoidal data seemed to appear and then to disappear for no apparent reason. Since these components appeared to be harmonically related, overall harmonic distortion was examined. Fig. 15 illustrates the manner in which the amplitudes of the second harmonics of 40-, 60-, and 80-cps signals, originally recorded at 7.5 ips, varied as the scan rate was increased. The third harmonics of these same signals varied in a different manner; as shown in Fig. 16, each fell to some minimum value at a certain speed. These effects were the result of a nonlinear relationship introduced by a combination of the extremely-high-inductance heads used in the particular scan assembly involved (each measured approximately 2.5 henries) and the input circuit of the particular preamplifier used. Extreme caution must be observed at increased scan speeds in order to avoid introducing such conditions, which would alter the original data.

Another phenomenon observed during these tests involved the influence of minute, random magnetic fields. At very high scanning speeds, if the magnetic heads in the scan assembly encountered even the slightest of stray magnetic or electromagnetic fields, an appreciable electrical pulse was created; in some instances, this pulse completely masked data of interest which were being examined. Silver-carbon brushes were used with the first rotating-head assemblies. After an hour of operation at high rotational velocity, permanent magnetic properties had been induced in these brushes, and a severe transient was created at the frequency at which each head passed the magnetized area. To increase the complexity of the situation, all odd and even harmonics of this fundamental transient were present.

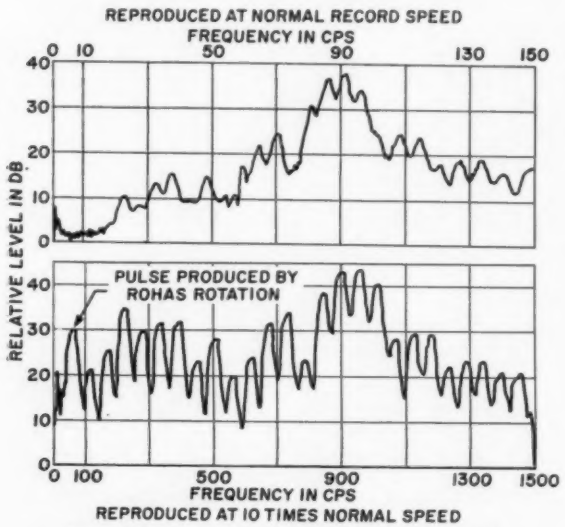

Fig. 17. Effect created by extraneous magnetic field.

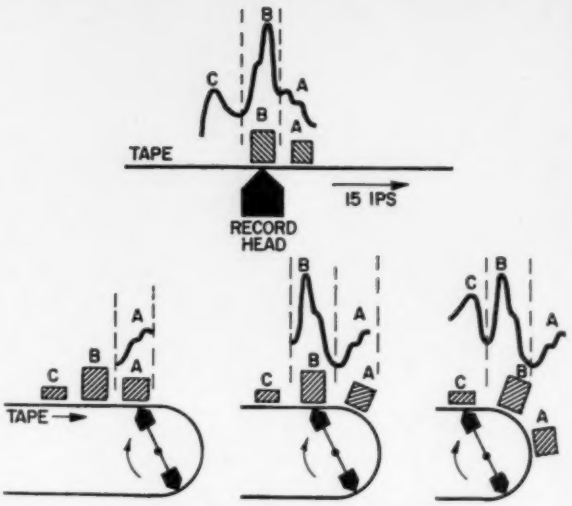

Fig. 18. Effect of reverse scanning.

This situation is illustrated in Fig. 17. The similarity to the situation which resulted from use of the open type of head is apparent, but now the fundamental tone is more completely obscured by the undesirable transients, even when scanned at the same speed at which the sample was recorded. As a result of this experience it was found necessary to demagnetize all possibly susceptible material near the scan heads.

An observation of psychological interest was the effect created when recordings of music were scanned in reverse from moving tapes. When scanning and tape speeds were adjusted in order to maintain a velocity differential equivalent to the speed at which the original recording was made, musical sounds were created which, to the casual listener, bore a startling resemblance to those encountered when scanning in the proper direction. The reason for this phenomenon is illustrated in Fig. 18. At the top is seen the normal record sequence partially completed. This recorded tape then proceeds to the scan head. As they enter the scan head, the individual segments of the magnetic pattern are scanned in reverse, but their sequence is scanned in the order in which they were originally recorded. The retentivity of the mind resulting from previous exposure to the melody and the ability of the ear to integrate instantaneous signal variations combine to complete the illusion. Speech treated in the same manner, however, was entirely unintelligible.

The response of a typical scan-head assembly to various wave lengths on stationary tape is illustrated in Fig. 19. For each wavelength scanned, peak response occurs when the ratio of scan speed to frequency observed by the scan

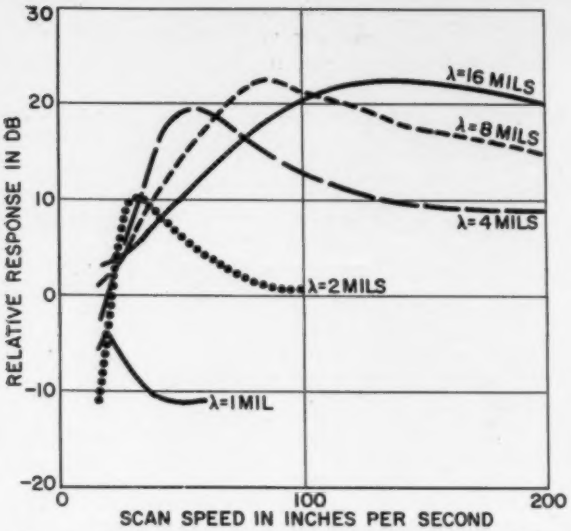

FIG. 19. Response of scan head to various wavelengths on stationary tape.

head is identical to the ratio between tape velocity and frequency established when the wave lengths indicated were originally recorded. Also, the individual curves stabilize at the resonant frequency of the magnetic heads involved.

SUMMARY

Development of a precision scanning device such as the ROHAS creates many problems which must be solved if the system is to be of maximum utility. Tolerances of all rotating diameters were maintained accurate to 0.0002 in. for run-out. High-precision bearings were used throughout. Wow in the tape transport, measured with the scan assembly stationary, does not exceed 0.5% at the lowest tape speed. Linear velocity of the scan head is rather unstable at speeds below 7.5 ips because of instantaneous instability in the shunt-wound dc drive motor.

Designed primarily to provide a tool for detailed investigation of sonar data, the application of the ROHAS to geophysical studies is obvious. Reflected sound waves from various earth strata may be observed individually or as a whole to determine their character and provide a basis for contour mapping and identification. However, experience in the use of the device is essential to insure that the data being processed do not reflect irregularities generated in the system. Other scanning heads, capable of performing unique functions, are currently being developed.

Although the technique of using rotating scan heads is not new, much knowledge concerning the utilization of rotating head assemblies in scientific studies has been gained as a result of the continued use of the ROHAS at the Underwater Sound Laboratory.

Discussion

Q. You have in effect a method of microscopic analysis of impulses. The problem here is the question of the resolution afforded by your method; for example, you were analyzing the patterns on an oscilloscope. Is it possible because of the limited resolution of even the best scopes that some of the peaks and dips are slurred over?

A. The graphs which showed analysis were not taken from an oscilloscope. They were taken from spectrum analyzers and represent actual electronic analysis. The oscillograms were shown merely to indicate how it is possible to dismember a given pulse and to look at it in parts, but the actual analysis was made with analyzing equipment, and not from oscilloscope observations.

Q. Have you used the technique of three dimensional pictorial representation of the sound spectrum, similar to the method developed at the Bell Telephone Laboratories?

A. No, we have not.

Q. Have you experimented with an all-metal face solid head, instead of the plastic head, to reduce the friction problem? I am referring to the contact surface between tape and head which in this case would be plastic and have high friction, while an all-metal head, around the pole pieces as used in computers and instrumentation, would reduce friction.

A. The second head that I showed, and referred to as a solid head, was all metal, except in the area where the heads themselves were located, which was plastic, for the following reason. The heads were aligned electrically by the usual method of alignment, i.e., we locked the assembly in place and aligned it as we normally do using alignment tape. The positioning of the heads to locate them diametrically opposite each other was done on a shadowgraph type of device, and, once they were in position, they were potted in this plastic so that they wouldn't move, but that is the only part of the whole assembly that is plastic.

Q. I can understand why you want to scan at a lower speed than the recording in order to get more detail, but what is your purpose in scanning at higher than original speed?

A. For one thing, in analyzing data, it is much easier to build very narrow filters for scanning over a spectrum. It is much easier to build very narrow filters designed to operate at high frequencies, and in a good many of the commercial analyzers, if you have some material to scan, say, in a band of 10 cycles to 150 cycles, this energy is converted up to around 90 kc and scanned with very narrow filters, maybe 2, 5, 10 cycles wide, and it is very easy to make such crystal filters for these high frequencies. Also it reduces the scanning time very much. For example, if we used these two-cycle filters for analysis at the speed at which the material is recorded, to get this fine grade detail would take us anywhere from 1½ to 3 hours to scan the audio spectrum, whereas by converting to high speed, we can do it in a matter of a few minutes. It speeds up analysis considerably. Also this is a big help to us because we do a tremendous amount of analysis with tape loops, and this saves us an awful lot of loop cutting in analyzing pulses. Previously when we analyzed pulses, we had to rerecord the same pulse 15 or 20 times, and then spliced them all together to make a continuous loop. This gave effectively a steady state signal for the analyzer to see, but took a lot of time.

Q. Did you give any consideration before entering on the ROHAS job to recording once from your original data tape by digital means on to a drum and reconstructing your analog data from the digital recording on the drum?

A. No, I presently don't have any device for doing that, but we are hoping to have such a device in the course of this next year.

THE AUTHOR

Mr. William S. Latham is associated with the United States Navy Underwater Sound Laboratory in Fort Trumbull, Connecticut.

Mr. Latham graduated in 1938 from the Capitol Radio Engineering Institute. He also attended specialized courses at New York University. From 1941 through 1943 he was an instructor in radio engineering theory at the Capitol Radio Engineering Institute. For the past 14 years he has been employed at the United States Navy Underwater Sound Laboratory, working in the field of sound and data recording. He now is head of the Recording Techniques Branch of the Scientific Data Acquisition and Analysis Division.

Mr. Latham has written many papers on magnetic devices, including "Limitations of Magnetic Tape", published in *Audio Engineering;* "Tape Life", presented at the 1955 Convention of the Institute of Radio Engineers, and "Multiplex Magnetic Data Recording Systems", which he presented at the 13th Underwater Acoustics Symposium.

He is a member of the Institute of Radio Engineers and its Professional Group on Audio, as well as being a charter member of the Audio Engineering Society.

An Analysis of Tape Noise in a 100-KC Bandwidth*

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The noise of various kinds of commercially available tape was measured in logit filter bands from 100 cps to 100 kc by means of standard and readily available equipment, with the exception of the filters.

The corrections necessary because of the use of the logit filters and the various electrical and physical characteristics of the head and the reproduce process are described and considered.

The results of the measurements are presented in terms of noise spectra as a function of the type of erasure, backing thickness, orientation of the magnetic coating, and tape speed. The actual noise voltages encountered are also shown.

INTRODUCTION

IN ANY MAGNETIC record-reproduce system, as in any communication system, the amount of information which may be stored or transmitted depends upon at least two factors. The first of these is the bandwidth available; the amount of information which may be stored or transmitted varies directly with the bandwidth. The second factor is the dynamic range of the system; the amount of information which may be stored or transmitted varies directly with the dynamic range. Of these two factors, the latter is affected by tape noise.

In magnetic recording, the two limits which describe the dynamic range are: (1) the maximum level at which a signal can be recorded without distortion and (2) the noise which is inherent in the system itself. This noise may be regarded as consisting of two components:

a. the noise associated with the recording and reproduce amplifiers, and,

b. that which is contributed by the process of passing the tape over the reproduce head.

Amplifier noise is essentially dependent on factors which can be controlled by design—within, of course, the limits set by the physical characteristics of the components used and the bandwidth desired. Tape noise is also a physical fact-of-life but it sets a limit to the minimum signal which can be recovered from the tape, regardless of the quality of the amplifiers involved. The thought here is that, even if amplifiers with no noise at all could be designed, there still would be noise in the reproduce process.

This noise, which is termed tape noise, is essentially white noise, the spectrum of which is modified by the combination of the electrical and the physical response of the head. In addition, this noise may be affected by instability of tape transport, by mechanical resonances of the tape, and by variations in degree of contact of the tape. Regardless of the actual mechanism of tape noise, it is a factor with which the audio engineer must contend.

There are many methods of recovering information from tape; the simplest of these is, perhaps, merely listening to what has been recorded. For more accurate information as to the spectrum of the original signal, however, it is usually necessary to resort to the use of filters. The purpose of the filter is to permit one particular component to be distinguished from the rest of the signal, or, in other words, to permit the energy associated with a particular frequency to be measured. Inherent in this process is a loss of knowledge of the nature of the wave shape of the signal; this loss is offset, however, by an increase in signal-to-noise ratio. This signal-to-noise ratio is the significant factor, for when it diminishes to approximately two, little information can be recovered unless correlation techniques are utilized. It is, therefore, important to have some quantitative information concerning the overall noise and, further, concerning the noise of tape itself, since tape noise is the ultimate limit.

* Paper presented at the Ninth Annual Convention of the Audio Engineering Society, New York, October 8, 1957. Paper received September 25, 1957.

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MEASUREMENT PROCEDURE

For the tape-noise measurements described in this paper, eight samples of tape were selected. These samples included the products of three manufacturers. The variables were tape speed, type of backing material (Mylar and acetate), thickness of backing, thickness of coating, type of magnetic dispersion (oriented and unoriented), and type of erase (bulk and high-frequency)

The technique used to measure tape noise was uncomplicated (see Fig. 1). The voltage generated in a ¼ in. playback head, as pre-erased tapes were run over it, was amplified, passed through filters of various bandwidths and geometric mean frequencies, and measured by means of a vtvm calibrated to read rms values of sine waves. The impedance curve of the playback head used to measure tape noise is shown in Fig. 2. In order to determine this curve, a constant voltage was fed across a 2-ohm resistor in series with the head, which was terminated in the first decade amplifier, and a vtvm was used to read the output. The resonant point occurs at approximately 11 kc. The noise spectrum, or system noise, of this combination is presented as the dotted curve in Fig. 3. It can be seen that the noise level peaks at approximately the resonant frequency of the head, as might be expected, and that, since the peak is very broad, the head has a relatively low Q. This curve, as are the others in this figure, is the noise-level spectrum reduced to an equivalent per-cycle basis. The other two curves are the noise spectra of the amplifier with the input shorted and with a 100K resistor across the input.

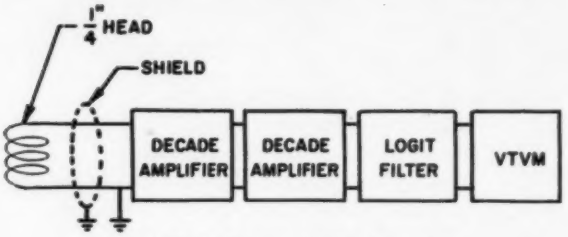

FIG. 1. Block diagram of measuring system.

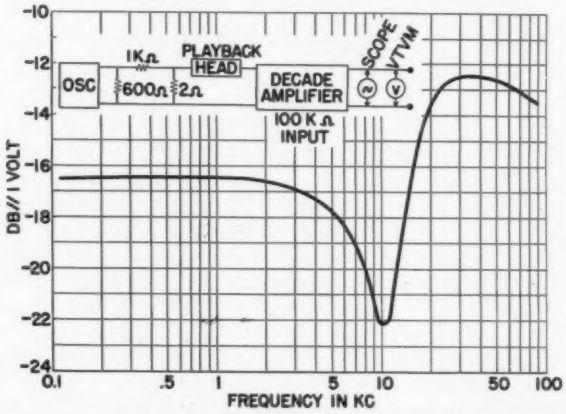

FIG. 2. Impedance curve of head terminated in decade amplifier.

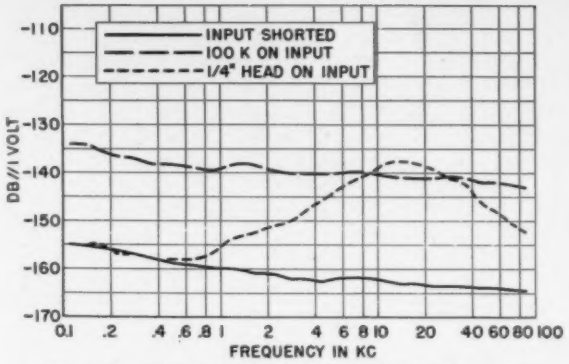

FIG. 3. Measuring system and decade amplifier noise spectra.

Figure 4 shows the response of the head to constant-current recording at two tape speeds. This is, of course, the usual response curve without equalization. Note the approximately 6-db-per-octave rise and the sharp fall-off above the peak. It is of interest to note that the peaks occur at approximately 10 db below one volt for the 60-ips curve and at approximately 15 db below one volt for the 30-ips curve.

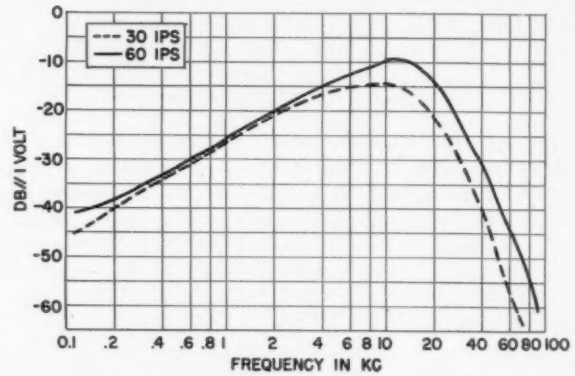

FIG. 4. Constant-current response of playback head.

The amplifiers used had fixed voltage gains of either 10 or 100 and were selected on the basis of bandwidth and low noise. The vtvm was selected because it is commonly used to read signal levels; since the noise measured was first passed through the filters, it is assumed that the use of this particular vtvm did not cause a significant error. Logit

filters were employed in these measurements because they were the only filters available which encompassed the frequency range from 100 cps to 100 kc. For those who may not be familiar with this type of filter, it should be pointed out that the upper and lower limiting frequencies of any one logit filter are in the ratio of $10^{0.1}$ or 1.259:1. The lower limiting frequency of the lowest filter band is 100 cps. The upper limiting frequency of any one filter is the lower limiting frequency of the next one. The geometric mean frequencies of any two contiguous filters are also in this ratio, and the bandwidth of any filter is a fixed percentage (23%) of the geometric mean frequency. The correction necessary to reduce the level read at the output of any one filter to an equivalent per-cycle basis is approximately a whole number of decibels; the exact number depends upon the individual filter.

The voltage levels read at the outputs of the various filters were corrected both for the gain of the amplifiers and for the filter widths, but no corrections were made for the electromechanical response of the head. The response of the head is of more or less standard form, and furthermore, a figure for tape noise appears to have no real meaning except as it relates to a particular head. In any case, the purpose of these measurements was to compare tapes. The figure obtained represents the noise which would appear at the output of a filter with a bandwidth of one cycle placed on the terminals of the playback head. It is the same figure as that which would be obtained if the spectrum of the noise were flat over the interval of bandwidth bounded by the frequency limits of the filter, that is, if the noise in every increment of bandwidth of the filter were the same as in every other increment of bandwidth of the particular filter.

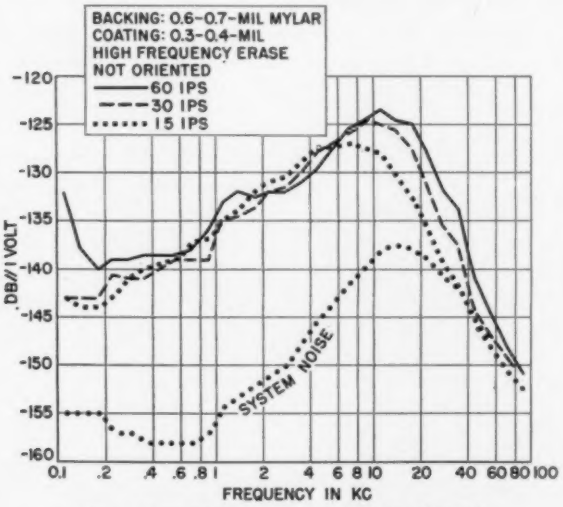

FIG. 5. Tape-noise spectra as a function of speed.

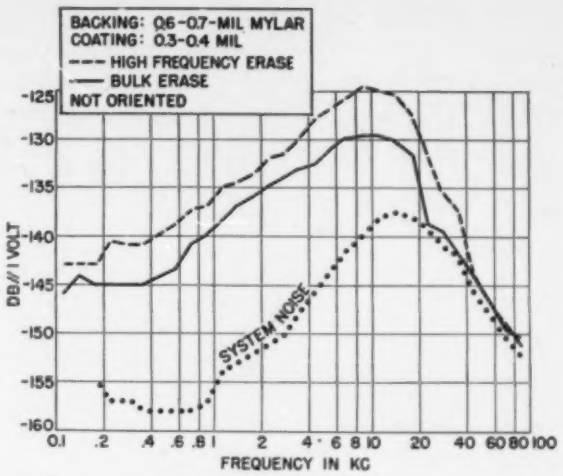

FIG. 6. Tape-noise spectra as a function of erase, unoriented dispersion.

When the corrected values for the levels of the noise were plotted, the geometric mean frequencies of the filter bands were used as abscissas and the levels relative to one volt in decibels were used as ordinates. These points were connected by straight lines.

RESULTS OF THE MEASUREMENTS

There appear to be two obvious factors which can affect the level and the spectrum of tape noise. The first of these is tape speed. It may be seen from Fig. 5 that as the tape speed changes, the overall level of the noise changes somewhat. In addition, it is apparent that as the speed increases, the peak levels rise and the frequencies at which the peaks occur also rise. It should be noted that at the upper end of the graph, from about 40 kc to 100 kc, the tape noise drops to about the level of the system noise, except for the highest tape speed. This indicates that system noise rather than tape noise was measured at these frequencies. This particular graph was selected in order to show both the rise in the peak levels and the change in the frequencies at which these peak levels occur. In not all of the tape-speed runs was there so great a separation of the peak levels, nor was the change in frequency at the peak levels so pronounced. In general, however, all the curves of tape noise as a function of frequency with tape speed as a parameter illustrate the following effects: (1) a slight rise in overall level with speed, (2) an increase in peak level with speed, and (3) an increase of the frequency at which the peak level occurs with speed.

The second factor which would most likely affect tape noise is the type of erase employed. Shown in Fig. 6 is a

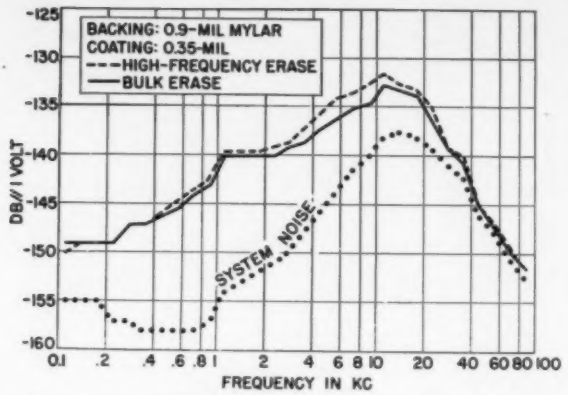

FIG. 7. Tape-noise spectra as a function of erase, oriented dispersion.

comparison of the effect of two types of erase when used on a tape on which the magnetic dispersion was unoriented. The two types of erase are bulk erase at the power-line frequency and high-frequency erase. The latter was the normal erase method provided by the machine in the record mode of operation, with the bias and erase in operation but with no signal applied, and with the tape run across the heads at 30 ips. The curves shown are of the noise generated in the head where the erased tapes were run over the head again at 30 ips. As in all these graphs, the reproduce amplifier with equalization provided with the recorder was not used. It can be seen that the noise of the tape when bulk erased is somewhat less than the noise generated by the tape after it has been erased at the higher frequency. It should be noted that in this case the magnetic coating was unoriented.

In order to determine whether or not the orientation or lack of orientation affected the efficacy of the erase used, a tape on which the dispersion was oriented was erased by both methods, and measurements of the tape noise were made. The results of these measurements are shown in Fig. 7. It can be seen that in this case the difference in the noise generated when the different types of erase were used has diminished. In this particular instance, the difference seems insignificant, but, as shown in the previous figure, the bulk-erase method is more efficient. In all, eight tapes were tested in this manner, and for each it was found that the bulk-erase method resulted in a lower level of tape noise at each of three tape speeds (15, 30, and 60 ips). It is not true, however, that in all cases the efficacy of the bulk erase was affected so greatly by the orientation or lack of orientation of the magnetic dispersion.

There was a possibility that the order in which the tapes were erased and tested could affect the results or that the exposure of the tape to the bias and to record-amplifier noise during high-frequency erase could increase the noise. In order to determine whether or not any of these factors had an effect, the order of erase was reversed, the tape was erased with the record head disconnected and then with the record head connected but with a 500-ohm resistor on the input of the record amplifier. In no case was there a significant change in the noise levels measured.

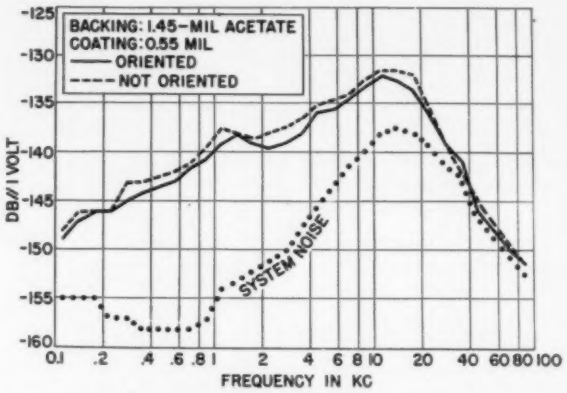

FIG. 8. Tape-noise spectra as a function of orientation, acetate backing.

Up to this point, the two more obvious factors which are likely to affect the tape noise have been considered; now a third factor, the orientation or lack of orientation of the magnetic dispersion, may be discussed. Four tapes were bulk erased, and the noise was measured as they were run over the head at 30 ips. Two of the tapes had acetate backing; the dispersion on one was oriented, while that on the other was unoriented. A comparison of the two is shown in Fig. 8. It can be seen that the tape with the oriented dispersion exhibited a slightly lower noise level. In Fig. 9

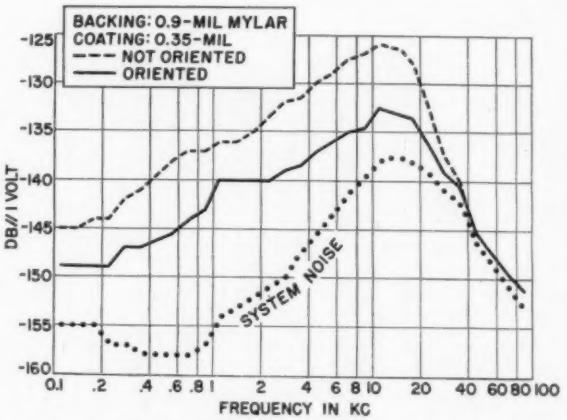

FIG. 9. Tape-noise spectra as a function or orientation, Mylar backing.

are presented the results of the same kind of comparison, but in this instance the backing was Mylar and the backing thickness was less. There is a greater difference in noise levels for the two Mylar-backed tapes; the one with the oriented dispersion had considerably less noise. It was found that of the three tapes tested with acetate backing of approximately equal thickness and with the same coating thickness, the one with the oriented magnetic dispersion had less noise than the two which had unoriented dispersions. This characteristic also held true for four Mylar-backed tapes; in other words, each tape with oriented dispersion has less noise than either of the two tapes with unoriented magnetic dispersion. It should be mentioned, however, that the Mylar-backed tapes had different backing thicknesses and different coating thicknesses.

There are several other factors which could affect the amount of noise generated as the tape passes over the head. The first of these is the kind of backing. Fig. 10 gives a

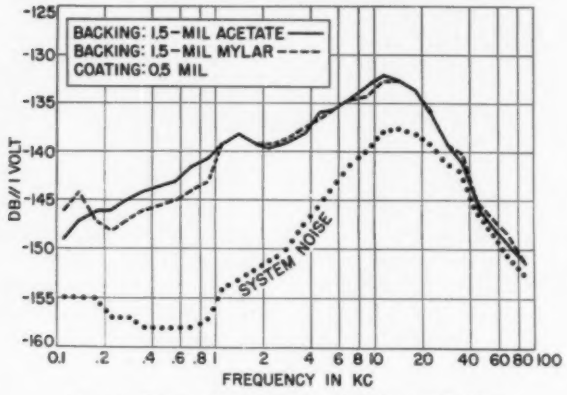

FIG. 10. Tape-noise spectra as a function of backing.

comparison of the noise of two tapes, each of which had an oriented dispersion of approximately 0.5 mil and each of which had a backing of approximately 1.5 mils. In one case, the backing is Mylar; in the other, it was acetate. It so happens that both of these tapes were produced by the same manufacturer. It can be seen that, except at the lower frequencies, there is little difference between the two. On the basis of noise, then, it may be concluded that there is little choice between acetate and Mylar.

Coating thickness was considered next. Fig. 11 shows the noise spectra of two tapes, both with 1.45-mil acetate backing and both were oriented dispersions. The dispersion thickness on one is approximately 0.65 mil, the other is approximately 0.55 mil. Although the 0.1-mil difference in thickness is small, it represents approximately 20 per cent. It can be seen that there is little difference in noise level at the upper frequencies, but at the lower

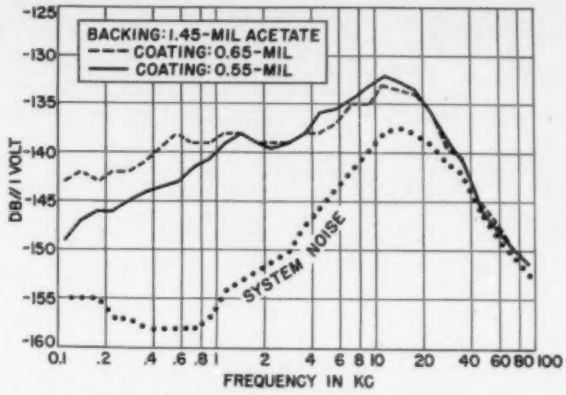

FIG. 11. Tape-noise spectra as a function of coating thickness.

frequencies, the tape with the greater dispersion thickness has a higher noise level. These two tapes were made by different manufacturers.

The thickness of the backing itself was now considered. Here, two comparisons were made. The first, Fig. 12,

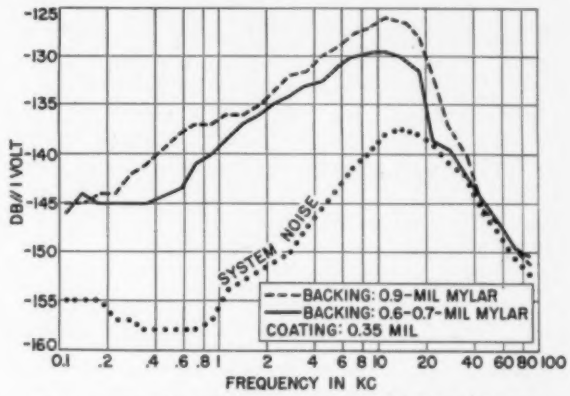

FIG. 12. Tape-noise spectra as a function of backing thickness.

gives the spectra of two tapes, each of which had an unoriented, polished coating of approximately 0.35 mil. Both tapes were produced by the same manufacturer. The backing of one is approximately 0.9 mil thick; the other is 0.6 to 0.7 mil thick. It may be seen that the tape with the thicker backing has a higher noise level. The second comparison, Fig. 13, shows little difference between the spectra of two tapes with different backing thicknesses. Here, however, the coating thickness varied also. The other factors, including the manufacturer, were the same. Under these circumstances, the tests of the effect of both coating thickness and backing thickness must be regarded as inconclusive.

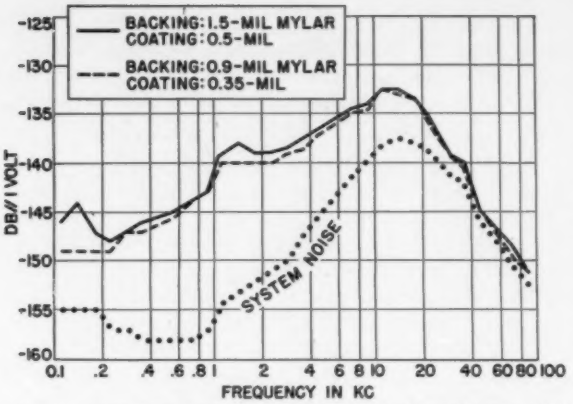

FIG. 13. Tape-noise spectra as a function of backing thickness (different coating thickness).

Fig. 14 shows the somewhat idealized noise spectra of two tapes with respect to the noise of a playback amplifier. This amplifier noise spectrum has been normalized and is plotted as a straight line. In order to obtain the upper two curves, the noise level of the amplifier in each logit filter band was subtracted from the noise level of each tape in the corresponding band and the difference was plotted. The lower curve is the spectrum of a 1.5-mil Mylar-backed tape with an oriented 0.55-mil magnetic dispersion. It is typical of the spectra of several tapes with oriented dispersions and represents about the lowest noise level measured. The upper curve is the spectrum of a 0.9-mil Mylar-backed tape with an unoriented 0.35-mil magnetic coating. It was the highest noise level measured. It can be seen that the maximum difference is close to 6 db.

SUMMARY

In general, the results of these measurements indicate the following:

a. As tape speed is increased, tape noise increases.

b. Bulk-erased tapes have a lower noise level than high-frequency-erased tapes, at least where the high-frequency erase is made on the particular machine used for the measurements.

c. Tapes with oriented dispersion are less noisy than those with unoriented dispersion.

d. The use of acetate as opposed to Mylar for tape backing causes little change in noise levels.

e. In the opinion of the author, there appears to be some evidence that neither the backing thickness nor the coating thickness is particularly significant.

In regard to the high-frequency erase, it has been pointed out elsewhere that erasure with a non-symmetrical wave may result in a dc component which causes a higher noise level. Perhaps this is the reason for the results shown in this paper, although a visual examination of the erase wave shape indicated no lack of symmetry.

A comparison of normal signal levels with the noise levels indicate that at the point of maximum response, the signal-to-noise ratio of a pure tone to equivalent noise in a one-cycle band is of the order of 120 db. This ratio should hold, regardless of the head used, but it must be pointed out that this large order of signal-to-noise ratio can be obtained only when filters are used. No significant improvement in broad-band signal-to-noise ratio can be obtained as a result of tape selection. However, careful selection of tape for use with filters can result in a measurable improvement in the signal-to-noise ratio.

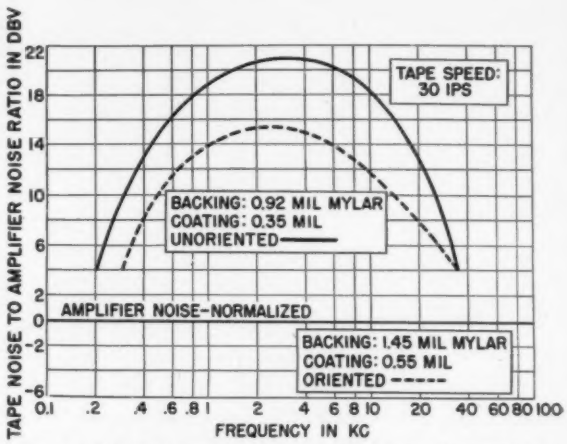

FIG. 14. Idealized tape-noise spectra, amplifier noise normalized.

Discussion

Q. Do you know if this particular system had a dual gap type of erase head?

A. No, it did not; it had a single gap.

Q. I would strongly recommend that this be tried and preferably for a construction whereby you can use a high frequency erase. I believe you will find your noise much below the bulk erasure.

A. Well, we will just have to find that out.

Q. The impedance curve that you show on the head (Fig. 2), it seems very unusual that you have a different voltage. Nothing was mentioned about constant current or constant voltage at the input.

A. It was a constant voltage input.

Q. Yes, it would have to be. But the head's function

in the recorder is as a constant current device when it is energized.

A. Yes, it is.

Q. In the runs comparing bulk erase vs. high frequency erase (Fig. 6 and 7), was an attempt made to have the tape not touch the record head during playing? Isn't there a chance of leakage flux from the erase head feeding the record head?

A. The only thing that was done there: as a check, we removed the record head from the circuit. It was still there, physically.

Q. Was any measurement made on the comparative noise between polished tape and unpolished tape?

A. No. The tapes which I used were tapes which had been in use; they were not virgin tapes. However, because of the fact that they had all been used and run over the heads at least once, I think this is almost equivalent to polishing. Otherwise, we did not make any comparison of polished vs. unpolished tape.

Q. If you normalize the frequency response in your head with a flux calibration, would you still make the statement that the signal-to-noise ratio per cycle or per unit bandwidth was proportional to tape speed? In essence when you make a statement that the noise or signal-to-noise ratio was dependent upon the tape speed, if you normalize the response of your head to include the frequency range that you were measuring the noise in, is this still true? It would seem from your data that the signal-to-noise ratio was the same on a per cycle or per unit bandwidth basis irrespective of the tape speed, so that the tape speed did nothing more than change the noise induction into what was a rather limited frequency response.

A. I think your question is, does a variation in tape speed change the signal-to-noise ratio on a per cycle or unit band basis? I don't think that it does.

Q. Did you make any attempt to correct the higher frequency region, i.e., to check this in the higher frequency region?

A. Actually, when I ran these tapes at 5 separate speeds, 15, 30, 48, 60, and 96 ips, and plotted the noise as a function of tape speed; at the upper two speeds, the 96 and the 60, the noise actually fell off a little faster than one might expect simply on the basis of the curves which I showed of the head response. The reason, I suspect, was that I was losing tape contact at the high speeds.

Q. You gave data for several different backing thicknesses, coating thicknesses and orientation, and said your tape came from stock, and probably a used stock. How do you know whether or not the tape was oriented or the particular dimensions of the tape?

A. In our runs eight samples were selected, their brand names were noted, and a code number was assigned to the tape. From that point on, the measurements were run referring only to the code numbers of the tapes. After the runs were plotted, we began to compare the data, and looked for and found differences. Then we went back to the original manufacturer's specifications for the tape and noted that a particular tape was oriented or not oriented, or that it was a particular type of backing.

Q. Were the figures you gave averages of several samples, or of only one sample?

A. We selected a 10½" roll of tape and this tape was run across the head several different times at several different speeds. We did not select a number of different samples of a manufacturer's product.

[Editor's Note. A further discussion of the sources of tape noise will be found in a recent paper by D. H. Howling, *Jour. Acoust. Soc. Amer.*, **28**, 977 (1956).]

THE AUTHOR

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High Power Transistor Audio Amplifiers*

MARVIN B. HERSCHER†

Radio Corporation of America, Camden, N. J.

Several models of high power audio amplifiers have been developed; each is capable of delivering 45 watts output. These amplifiers use a ribbon chassis for cooling and operate over an ambient temperature range of −10°C to +50°C. One amplifier uses a series type circuit and the other a quasi-complementary symmetry type circuit. Amplifier size and weight are reduced since neither circuit employs driver or output transformers.

INTRODUCTION

IN GENERAL, transistors offer the advantages of size and weight reduction, conservation of supply power, and greater reliability.

Until quite recently most transistor circuit development has been limited to low power applications and low transistor dissipations (in milliwatts). With the advent of higher power audio transistors, it became desirable to investigate the use of these devices in high power audio amplifiers where the transistors are operated at higher power dissipations and correspondingly higher junction temperatures. Under these conditions, techniques quite different from those used in low-power amplifiers had to be established. This paper will describe various design principles that enable newly available high power audio transistors to be utilized. (It should be pointed out that, since this project was a feasibility study, the transistors were occasionally used somewhat above their established ratings. In a commercial application, it is recommended that the transistors be used below their maximum ratings.)

Both the thermal and/or the electrical limitations impose an upper limit on the power handling capabilities of the transistor. When the transistors operate at high junction temperatures, the thermal considerations become quite important. Briefly, the thermal limitations are as follows: (1) For reliability considerations, the maximum junction temperature, as specified by the manufacturer, should not be exceeded; (2) The circuit must be stable thermally; that is, the chassis or other cooling facility employed must be capable of removing the heat generated by the transistor so as to maintain an equilibrium condition.

In essence, by providing a good thermal path from junction to air, and by maintaining a relatively stable dc operating point with temperature, the condition for stability may be met. Operating point stability may be obtained by stabilization (dc feedback) or temperature compensation (use of temperature-sensitive circuit elements).

The two power amplifier circuits to be discussed employ various techniques of stabilization and compensation which allow stable operation up to ambient temperatures of 50°C. Each amplifier can deliver 45 watts to a 4 ohm load. Of particular significance is the fact that neither a driver nor output transformer is employed in these circuits. The elimination of transformers in itself usually makes possible a considerable saving in size and weight, and often results in an improvement of the overall frequency response. Moreover, a greater amount of negative feedback is generally possible in the absence of transformers. Another interesting property of these circuits is their exclusive use of pnp transistors in the output stage.

QUASI-COMPLEMENTARY SYMMETRY AMPLIFIER

The first power amplifier circuit to be described is the quasi-complementary symmetry amplifier.[1] This is a convection-cooled amplifier designed to deliver 45 watts into a 4 ohm load over a temperature range of −10°C to +50°C. A photograph of the amplifier is shown in Fig. 1 and the circuit schematic is shown in Fig. 2. The amplifier has outside dimensions of 8½ x 6½ x 6½ inches and weighs about 10 lb.

The circuit consists of three stages: a *pnp* class-A driver stage; a complementary transistor pair, which acts as a phase splitter; and a power output stage, consisting of two *pnp* transistors in single-ended push-pull operation, capaci-

* Paper delivered at the Ninth Annual Convention of the Audio Engineering Society, New York, October 12, 1957. Paper received October 7, 1957.

† Development Engineer.

[1] H. C. Lin, "Quasi-Complementary Transistor Amplifier," *Electronics*, September 1956, pp. 173-175.

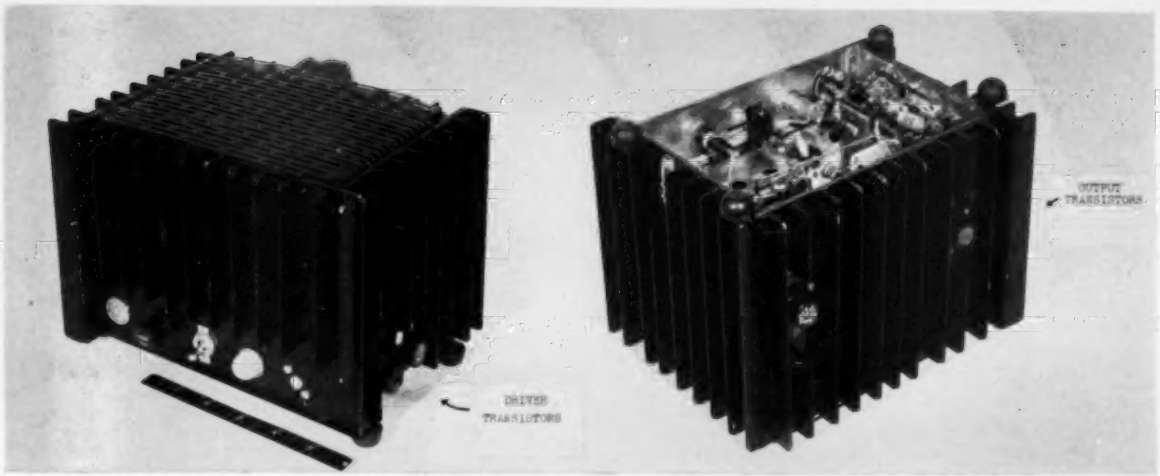

FIG. 1. 45-watt Quasi-complementary Amplifier. Left: Front view showing driver transistors. Right: Bottom view showing output transistors.

tively coupled to the load. The last two stages operate class B.

X_2 and X_4 operate as common collector amplifiers. When these transistors are conducting, the output current is B_2B_4 times the current supplied by the first stage, where B_2 and B_4 are the effective current gains of the phase-splitter and output stages. Similarly, the output current when X_3 and X_5 conduct is B_3B_5 times the current supplied by the first stage, where B_3 and B_5 are the effective current gains of the phase splitter and output stages. If $B_2B_4 = B_3B_5$, the input resistance presented to the first stage is equal to $B_2B_4R_L$, and the circuit is in balanced operation.

1. Output Stage

Fig. 2 shows the output stage which uses two RCA 2N301A transistors connected in series with the dc supply. For proper operation of the amplifier, these transistors should possess certain characteristics.

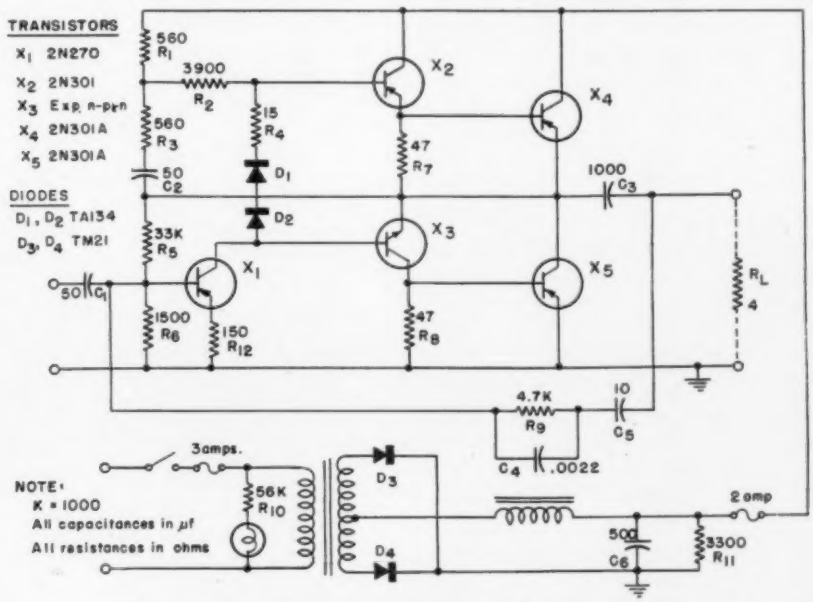

FIG. 2. Circuit diagram of 45-watt Quasi-complementary Amplifier.

One important property of these transistors is that they have a thermal resistance from junction to case of less than 1.3°C/watt. By close thermal coupling to the chassis, achieved by mounting the transistor on a Mylar insulator coated with silicone oil, a total thermal resistance from junction to air of about 3.0°C/watt is obtained. This resistance is sufficiently low so that the 10 to 12 watts dissipation (most severe condition) from each transistor may be stably transferred to the air. The low chassis thermal resistance of about 1.6°C/watt is obtained both by convection and radiation cooling from the large surface area of the ribbed chassis configuration, as shown in Fig. 1. The amplifier chassis is painted a dull black to aid heat transfer by radiation.

Another important property of the output transistors is their maximum collector-to-emitter breakdown voltage. This voltage which is dependent upon both the resistance connected between base and emitter and the junction temperature, decreases as the junction temperature is raised, and as the emitter-base resistance is increased (up to about 1000 ohms). The output transistors used were selected from stock such that their breakdown voltage exceeded 60 volts (at room temperature) with 47 ohms connected between base and emitter. This insures that the transistors operating in the actual circuit will not break down at higher temperatures. At peak signal swing the maximum inverse voltage applied to each output transistor is slightly less than the supply voltage (which is about 41 volts at full sinewave power output). Under normal operating condition, a good dc balance exists, and the center-point voltage, at the collector of X_5, is approximately equal to one-half the supply voltage.

The voltages appearing across resistors R_7 and R_8 provide a small forward bias to the base-emitter junctions of X_4 and X_5, as shown in Fig. 2. The resistors were chosen to be 47 ohms, since this provides a bias of about 0.15 volt (at 25°C) which is necessary to minimize the non-linear crossover region in the composite transfer characteristic of the class-B amplifier. It should be noted that the bias voltage is ultimately determined by the voltage drops across R_4, D_1, and D_2. D_1 and D_2 are RCA TA-134 developmental temperature-compensating diodes whose forward voltage drops decrease with increasing temperature and thus tend to hold the transistor emitter currents constant. This compensation is necessary because less forward base-emitter bias is required as the junction temperature is increased. A relatively constant operating point increases the thermal stability of the amplifier. For optimum temperature stability, three biasing diodes should be used in this circuit rather than two, since there are three emitter junctions in series.

It should be recognized that a penalty is paid in order to provide proper transistor bias and to obtain a lower distortion. This arises because of the selection of a small value of resistance for R_7 and R_8. Some signal power is lost (about 1 watt at maximum power output) in these resistors since they are in shunt across the base-emitter junctions of the output transistors, which have a large-signal input impedance of approximately 20 ohms.

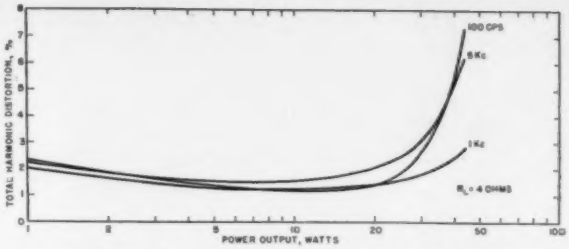

FIG. 3. Distortion vs. Power Output for 45-watt Quasi-complementary Amplifier.

A further property required of the output transistors is that they possess a large-signal current gain of at least 25 at 4 amperes of collector current. This requirement arises due to distortion considerations since the peak collector current that flows in the transistors is between 4 and 5 amperes. Because the output impedance of the driver stage is relatively low, variations of the transconductance for the output stage also are important. Measurements have shown that 2 to 1 variations in this characteristic may be tolerated.

The harmonic distortion of the amplifier at various power outputs is shown in Fig. 3. The distortion increases at higher power output because of the β falloff of the output transistors at high collector currents. The reactance of C_3 gives rise to an elliptical load line at low frequencies, and as a result clipping occurs at high power outputs. At higher frequencies, transistor phase shift (due to the low transistor cutoff frequencies) causes nonlinearities and increases the distortion.

2. Complementary Phase-Splitter Stage

As shown in Fig. 2, X_2 is a *pnp* (2N301A) transistor and X_3 is an experimental *npn* transistor. Each operates class B and serves to split the phase of the incoming signal from X_1. In order to allow the amplitude of the peak signal swing to approach the supply voltage, bootstrapping is applied by way of C_2 and R_3 across R_1. Without the bootstrap

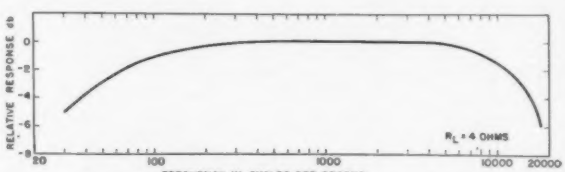

FIG. 4. Frequency response of 45-watt Quasi-complementary Amplifier.

action, the output voltage swing is limited to a value less than the supply voltage by virtue of the voltage drops in X_2 and X_4, and unsymmetrical clipping will occur at high power outputs. The value of R_3 was selected such that clipping was symmetrical at maximum (sine-wave) power output. Under this condition, the maximum collector efficiency of the output stage was increased to about 70% at room temperature.

The frequency response of the amplifier is shown in Fig. 4. The 3 db points are about 50 cps and 14 kc. The relatively low β cutoff frequencies of the power transistors used in the circuit limit the high frequency response of the amplifier. The low frequency response is limited primarily by the coupling capacitor C_3.

3. Driver Stage

X_1 is a medium power transistor (2N270) which acts as a class-A driver. Since the biasing of the following stages is strongly dependent upon the direct current flowing in the collector of this transistor, the temperature stability of this stage is important. The transistor is biased through resistor R_5 which is connected to the midpoint of the output stage, and thereby provides both dc and ac negative feedback. The temperature stability of this stage is further increased by virtue of emitter current stabilization provided by the emitter resistance R_{12} in conjunction with R_6.

The source impedance driving this amplifier should nominally be 500 or 600 ohms for proper performance. About 9 db of negative feedback is applied through R_9 around the entire amplifier to the base of X_1. C_4 is connected in parallel with R_9 to give a step-response in the feedback loop for stability.

At full power output, the power gain of the amplifier is about 41.8 db. The input impedance of the amplifier is about 200 ohms at 1000 cps, and the output impedance is about 1.6 ohms.

4. Power Supply

The power supply occupies about one-half the physical volume of the overall amplifier. This is necessary because of the large supply currents required to produce the high power outputs obtained. Full-wave rectification of the 60 cycle ac supply voltage is obtained by the use of silicon rectifiers followed by a choke-input filter which provides relatively good regulation and filtering. At full-signal output, the direct current is approximately 1.6 amperes at about 41 volts. The quiescent direct current at room temperature is about 70 ma, with no-signal voltage of about 54 volts. The hum at maximum signal output is approximately –15 dbm.

SERIES AMPLIFIER

The second high-power transformerless circuit to be described is the series amplifier, which is shown in Fig. 5. The

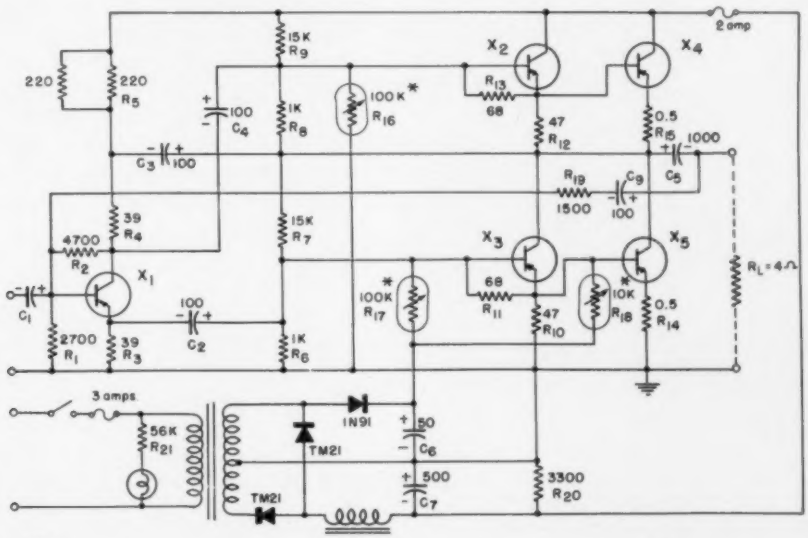

FIG. 5. Circuit diagram of 45-watt Series Amplifier.

circuit uses all transistors of like conductivity and requires no driver or output transformers. The series amplifier consists of a split-load phase inverter, capacitively coupled to a class-B common-collector driver, which, in turn, is direct coupled to the class-B common emitter power output stage. The driver and output stages are each in series for the dc collector supply.

This amplifier also weighs about 10 lb and is quite similar in size and physical layout to the quasi-complementary amplifier described above. The series amplifier is convection-cooled, uses 2N301 and 2N301A transistors throughout, and can deliver 45 watts to a 4 ohm load.

1. Power Output Stage

The series circuit, shown in Fig. 5, uses a pair of 2N301A transistors in the output stage. X_4 and X_5 operate in the common-emitter mode and are capacitively coupled to the load. The output stage operates class-B; therefore, with oppositely phased voltages applied to the bases of these transistors, the ac collector currents are additive in the load. Hence, X_4 and X5 are in series for the dc collector supply and in parallel for the ac signals.

The output transistors employed in this circuit were selected for the same properties as the corresponding transistors used in the quasi-complementary amplifier. These properties are: (1) a junction-to-case thermal resistance less than 1.3°C/watt, (2) a collector-to-emitter breakdown voltage (with a base-emitter resistor of 47 ohms) in excess of 60 volts, (3) a large-signal current gain of at least 25 at 4 amperes of collector current, (4) a variation in transconductance not to exceed 2 to 1.

It might be pointed out again that the reasonably acceptable linearity of the transconductance characteristic for these power transistors shows the desirability of driving large signal amplifiers from a low-impedance source, i.e., a voltage source. Lower distortion will result under this condition of drive than will occur if the transistors are driven from a high source impedance, i.e., a current source. This is true because of the relative nonlinearity of the current transfer characteristic caused by β-falloff. In the series circuit, a relatively low source impedance is provided for transistors X_4 and X_5 by virtue of the low output impedance provided by the common-collector driver stage.

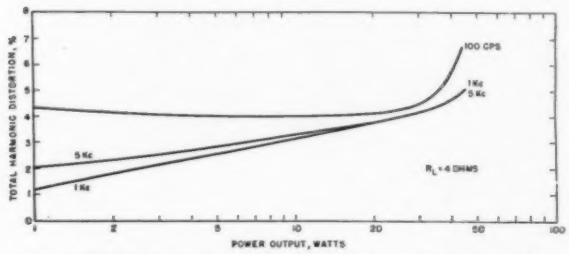

FIG. 6. Distortion vs. Power Output for 45-watt Series Amplifier.

The resultant distortion characteristics for this amplifier are shown in Fig. 6. The distortion may be reduced at low frequencies by increasing the values of C_2, C_3, and C_4. The ½-ohm resistors in series with the emitter of each output transistor improve the dc circuit stabilization for the output stage and also reduces distortion, but at the expense of a decrease in power gain and power output. The overall collector conversion efficiency (including the power lost in these resistors) is still about 65% at maximum power output.

The frequency response of the amplifier is shown in Fig. 7.

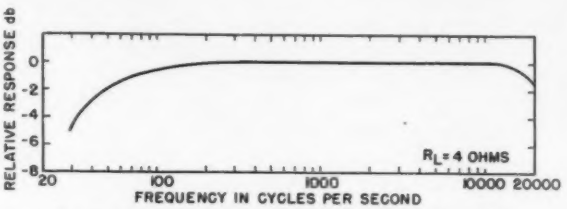

FIG. 7. Frequency response of 45-watt Series Amplifier.

The 3 db points are about 40 cps and 30 kc. The high-frequency response is limited by the β-cutoff frequency of the transistors and is highly dependent on the source impedance and the r'_{bb} of the transistors. The best frequency response for a common-emitter stage is obtained when it is driven from a low source impedance. Therefore, it is also desirable that r'_{bb} be as low as possible. The 2N301 and 2N301A transistors used in the circuit have an r'_{bb} of about 20 or 30 ohms. The preceding stage, being common collector, provides the desired low source impedance for the output stage. The low-frequency response is limited mainly by coupling capacitor C_3.

2. Series Driver Stage

The driver stage also uses a pair of 2N301A transistors which are connected in an emitter-follower (common-collector) configuration. This stage operates class-B and is direct-coupled to the output stage. Direct coupling eliminates a type of crossover distortion that occurs with capacitor coupling. This distortion would arise because the time constants of the charge and discharge paths of the coupling capacitor would be different during conduction and non-conduction. This difference would cause a reverse dc bias to be applied to the base-emitter junction, and this bias would then be dependent upon the signal level. The result would be an increase in distortion, since the forward base-emitter bias, normally applied to minimize crossover distortion, would be nullified.

This problem is encountered in the use of coupling capacitors C_2, C_3, and C_4 but is greatly reduced in the driver stage by resistors R_{13} and R_{11}, connected between the base and emitter of X_2 and X_3, respectively. The effect of these resistors[2] is to linearize the input impedance presented to the phase inverter, both during conduction and non-conduction. With a low impedance discharge path provided for these capacitors during non-conduction, the tendency for a charge to develop on the capacitor and to produce crossover distortion is reduced.

3. Phase Inverter

Transistor X_1 is a 2N301 transistor and is used as a split-load phase inverter which feeds driver transistors X_2 and X_3. This stage operates class-A and is biased at approximately 160 ma collector current, with 35 volts between the collector and emitter. This permits sufficient signal to be applied to the driver stage without introducing clipping at maximum power output. With no signal, this transistor dissipates about 5.5 watts and is closely coupled thermally to the ribbed chassis which acts as the heat dissipator.

Resistors R_3 and R_4 insure a low source impedance for the driver transistors. The impedance (for transistors of similar characteristics in the upper and lower halves) presented by the upper half of the driver-output transistor combination is essentially equal to that presented by the lower half, since, in each case there is a common-emitter stage preceded by a common-collector stage. This means that variations in the load impedance will be reflected to the phase inverter in a similar manner for the upper and lower halves, and the amplifier will thereby be in balanced operation. By virtue of splitting the collector load, and feeding the upper half of the amplifier from R_4, an essentially balanced output voltage is obtained.

Inherent negative feedback exists in the amplifier by virtue of the phase splitter configuration, the common collector driver stage (100% negative voltage feedback), and the unbypassed emitter resistors in the output stage. In addition, about 8 db of negative feedback is applied through a resistor R_{10} in series with a capacitor C_9 around the entire amplifier. (The amplifier should be driven from a source having an impedance of about 500 to 600 ohms.) In order to be able to drive the upper half of the amplifier close to the collector supply voltage, bootstrapping is employed in a manner similar to that used in the quasi-complementary amplifier. This is accomplished through the action of capacitor C_3 which is returned from the output to the junction of R_4 and R_5.

At full power output, the power gain of the series amplifier is about 30.6 db. The input impedance of the amplifier is about 113 ohms at 1000 cps, and the output impedance is about 2.5 ohms.

4. Bias Considerations for the Driver and Output Stages

In order to eliminate the effects of crossover distortion caused by the non-linear transfer characteristics of transistors at low signal levels, a small forward quiescent dc base-emitter bias voltage is required. Optimum bias voltage is obtained for the driver stages by the voltage divider action of resistors R_8 and R_9 in conjunction with R_{12} and R_{13} for the upper transistor and resistors R_6 and R_7 in conjunction with R_{10} and R_{11} for the lower transistor. At room temperature (28°C) the quiescent current for the driver stage is about 8 ma. Bias for the output transistors is obtained from the voltage drop across the emitter resistors R_{10} and R_{12} which are in series with emitters of X_3 and X_2, respectively. This bias is strongly dependent upon the quiescent current of the driver stage and the voltage divider network previously described. Quiescent current in the output stage is about 50 ma at room temperature.

As ambient temperature is increased, the operating points of the driver- and output stage change, since both the saturation current and the input conductance increase.[3] The problem of dc stabilization for the output stage is further complicated by virtue of direct coupling of the driver output stages. As temperature increases, the driver I_{co} increases, thereby increasing the forward voltage bias for the output stage. Simultaneously, the output transistor I_{co} is increasing and causes the quiescent current for the output stage to increase further. The ½-ohm resistors, R_{14} and R_{15}, in the

[2] A. I. Aronson, "Transistor Audio Amplifiers," *Transistors I*, RCA Laboratories, pp. 515-535.

[3] H. C. Lin and A. A. Barco, "Temperature Effects in Circuits Using Junction Transistors," *Transistors I*, RCA Laboratories, pp. 369-402.

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While an undergraduate, Mr. Herscher was employed by the Frankford Arsenal in Philadelphia under a co-operative training program. After graduation, he joined the circuit development group of RCA Defense Electronic Products, working primarily on transistor noise studies. He left RCA in 1954 for two years of active duty in the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey. In 1956, he returned to RCA, and resumed his work on transistor audio and pulse circuitry. He is presently working on advanced communication systems.

Marvin Herscher is a member of the Institute of Radio Engineers, the American Institute of Electrical Engineers and the Eta Kappa Nu and Tau Beta Pi fraternities.

output stage aid in stabilization of this stage by providing a negative current feedback that tends to maintain the output quiescent collector current constant. In the common-collector driver stage, degenerative direct current feedback is obtained by virtue of resistors R_{10} and R_6 in the lower transistor, and resistors R_{12} and R_8 for the upper transistor.

The dc operating point of the output stage is further stabilized by use of thermistor compensation. These thermistors are mounted on the chassis near the output transistors so as to compensate more closely the change in junction temperature rather than ambient temperature. Thermistors R_{16}, R_{17}, and R_{18} are connected in the circuit to provide a base-to-emitter voltage for the driver transistors which decreases with temperature. This action tends to maintain the driver emitter current constant with temperature. A positive bias supply is used to compensate the transistors at higher temperatures, since it is actually necessary to apply a reverse bias to the base-emitter junction to maintain a relatively constant operating point at elevated temperatures. The use of thermistors reduces the tendency for the quiescent collector current in the output stage to change with temperature, with the result that the amplifier performs satisfactorily throughout a temperature range of $-10°C$ to $+50°C$. At low temperatures, cross-over distortion is increased due to the inability of the thermistor networks to adequately compensate the output transistors.

5. Power Supply

The power supply for the series amplifier is essentially the same as that used in the quasi-complementary amplifier. It consists of two silicon rectifiers in a full-wave circuit and a choke input filter. An additional positive supply for bias compensation is obtained from a IN91 diode half-wave rectifier. The no-load voltage for the collector supply is about 58 volts. The supply voltage drops to about 45 volts at full power output with a direct-current of about 1.55 amperes. The power-supply ripple in the load with maximum signal is about -15 dbm.

A Continuous Loop Magnetic Tape Cartridge*

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Continuous magazine tape loops have application in educational and training devices, point-of-sale devices, home recording, display controls, industrial controls, telemetering, etc. Magazines, cartridges, and equipment designed to operate continuous magnetic tape loops present many engineering problems not usually encountered in standard two-reel techniques. Because the inside strand of the endless loop is pulled from the center and returned to the outside circumference of the tape mass, there is a resultant sliding action between each adjacent tape strand. Tape loops therefore require special handling devices and lubrication treatment to overcome malfunction and complete binding.

The ultimate quality of electronic and mechanical performance of a continuous tape loop is comparable to standard tape performance. A continuous tape magazine has been designed to convert most standard tape machines to operate continuously. Also, a cartridge and mechanism has been developed to thread and play the tape automatically by simply inserting the cartridge.

INTRODUCTION

ALTHOUGH THE GROWTH of the magnetic tape market has been tremendous, the use of tape recorders has not begun to reach its "mass market" potential. Consumers are reluctant to master the skill of handling reels, loading the machine, rewinding, etc. The industry has long recognized the need for a simpler method to thread and rewind the tape in order to stimulate consumer acceptance. One simplified method, with great possibilities, is the continuous tape loop. Such a continuous tape loop designed to fit most standard machines has been on the market for about five years, but it does not meet the need for a "foolproof" self-threading operation. It has, however, served as the foundation for the recent development of a self-theading tape cartridge which is the subject of this paper.

PRINCIPLES OF CONTINUOUS LOOP OPERATION

A continuous tape loop is formed by winding tape around a circular hub and splicing the end of the tape from the center to the end of the tape at the outermost convolution (Fig. 1). A continuous tape loop strand operating at a constant velocity must emerge from the innermost convolution and return to the outermost convolution of the tape mass. Since the tape strand is driven at a constant linear velocity there results a difference in the angular velocity of each tape convolution. Therefore, each tape convolution within the mass is constantly adjusting by sliding along an adjacent tape convolution.

Another important factor in continuous tape operation is "loop-size." Correct loop-size is a function of the number of feet in the tape-mass and lubrication of the tape. For a given number of feet in a continuous tape loop there is an optimum loop size.[1] The "operating-loop" is that loop which is required for the threading path when the continuous tape loop is in operation. The tape which is taken up in the tape-mass during operation is called "slack-loop." Therefore, the loop-size is the sum of the slack-loop and the operating-loop. The operating-loop is a constant for a particular threading path; whereas, the slack-loop is a function of the tape footage load.

If, for example, the slack-loop is too small, the force necessary to pull the tape strand from the inner feed diameter will increase. The increased feed tension is due to greater frictional drag within the tape-mass resulting from a greater normal force between adjacent sliding tape strands. Starting with essentially a zero slack-loop for a given footage load, and incrementally increasing the loop-size, the feed tension incrementally decreases until the point is reached where further increase in slack-loop size no longer

* Paper delivered by Mr. Ralph Cousino at the Ninth Annual Convention of the Audio Engineering Society, New York, October 10, 1957. Manuscript received October 17, 1957.

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[1] "Recording And Loading Instructions For Continuous Tape Magazines No. 5400 and 5600," Technical Bulletin #105, American Molded Products Company.

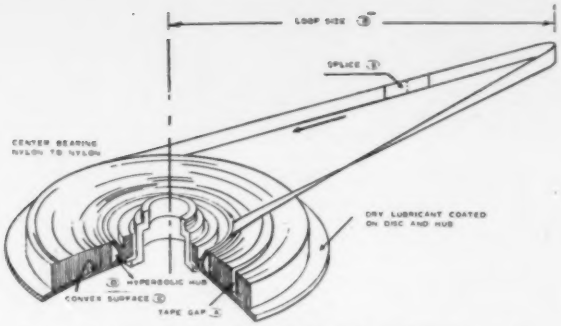


FIG. 1. Cutaway section of disc, hub, and continuous tape loop.

decreases the feed tension. This tension is called the "free slack-loop running tension."

During the process of increasing the slack-loop size a "tape-gap," as illustrated in A, Fig. 1, will form in the tape-mass, which increases with slack-loop size. If the slack-loop size is further increased the tape-gap in the tape mass becomes very large; this causes an erratic operation because it shifts position in the tape mass and the tension in the take-up and feed strand is not stable. The optimum slack-loop size is that which is enough larger than the free slack-loop to allow a very small tape-gap to form during the first five or ten minutes of operation.

Loop-size can be measured by taking up the loose slack with a 7 oz. pull on the outer strand of the tape mass, thereby resulting in a tight wind. Loop-size is the measurement from the center of the tape mass to the outermost point in the taut loop as shown in B, Fig. 1.

MAGAZINE FOR HANDLING TAPE IN A CONTINUOUS LOOP

A tape magazine consists of a disc, hub and a continuous tape loop with a protective cover and external threading loop. This is designed to fit most standard tape recorders, converting them for continuous operation (Fig. 2).

The protective cover is provided with guide slots to accommodate operation of the magazine in either a clockwise or counter-clockwise direction, as required to meet present recorder variations as can be seen in Fig. 2.

Some recorders with threading paths or reel spindles that do not accommodate the magazine can be adapted by means of a vacuum cup mounted spindle accessory.

Both the magazine and cartridges have a rotating disc and hub, which, when properly designed, provide for the most efficient operation of a continuous loop. In order to maintain the necessary even distribution of the tape, which normally has a tendency to be asymmetrical, the rotating disc is formed with a slightly convex surface (C, Fig. 1) to which a special surface lubrication is applied. As each tape strand moves from the outside diameter it climbs the convex lubricated surface, maintaining a symmetrically circular shape. This results in smoother and more even sliding of adjacent tape strands throughout the tape mass. The disc is rotating as the inner tape strand is pulled from the center hub driving the hub and the attached disc. The hub approximates a hyperbolic section (D, Fig. 1) and is designed to support the entire inner edge of the tape as it is pulled from the center. This hyperbolic section protects the tape from "edge-curl" and binding, inherent in other forms of hub sectioning.

SELF-THREADING CARTRIDGE DESIGN

Although the above stated principles of continuous tape operation were firmly established and successfully field tested as an accessory to standard tape recorders, many new considerations presented themselves in converting these principles into a self-threading cartridge design.

As a guide to the project, a list of important basic design objectives was established which greatly influenced the final design. The eight major factors from this guide list were as follows:

1. To provide high mass-production at low cost;
2. To automatically thread and rewind the tape;
3. To protect the tape from damage and tampering when it is not loaded in the recorder;
4. To eliminate from the cartridge precision guides, capstan idlers, pressure pads, and other precision parts, that might better be engineered into the cartridge handling machine;
5. To reduce the working parts and assembly work to a minimum;

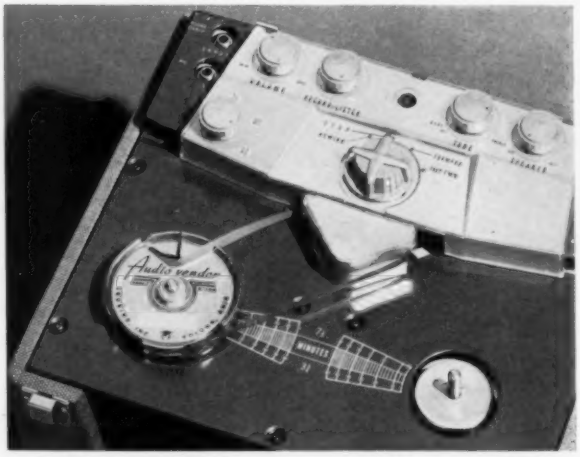
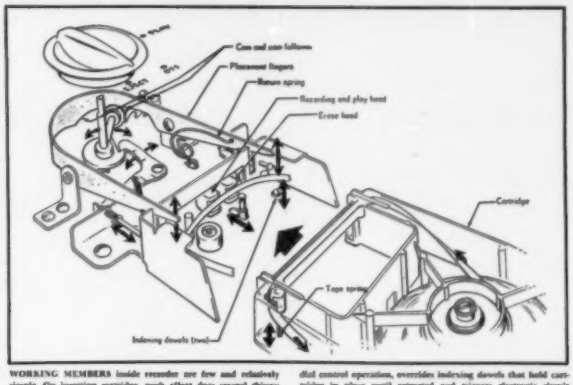


FIG. 2. Continuous magazine on standard tape recorder.

FIG. 3. Continuous cartridge, Long Play Model 430 and Short Play Model 410.



WORKING MEMBERS inside recorder are few and relatively simple. On inserting cartridge, push effort does several things: retracts tape guidepost which unhooks engineer hook permitting dial control operation, overrides indexing dowels that hold cartridge in place until retracted and triggers electronic circuit for playing.

FIG. 4. Schematic design of "push-in" cartridge, and its receptacle.

6. To provide for either small or large capacity loads interchangeably on the same handling mechanisms;
7. To design the cartridge size to allow for flexibility in tape handling discs (co-axial discs, continuous loops, removable magazines, etc.); and
8. To withstand reasonable shipping, handling, vibration and impact without affecting operational efficiency.

Consideration of the foregoing factors has led to the development of two cartridges now in production.[2] The smaller Model 410 meets the short-play requirements. The larger Model 430 Echomatic cartridge is designed to meet long-play requirements (Fig. 3).

Both designs provide for mass-production at low cost through the use of high-speed plastic injection molding. The threading loop of the tape is held upward in a protected channel (A, Fig. 4) by means of spring-loaded nylon tape-lifters (B, Fig. 4). Automatic threading is achieved in the cartridge handling mechanism by depressing the tape lifters. This action lowers the tape into proper alignment for the machine to handle the tape as in conventional machine design (Fig. 4). All of the working parts are assembled without tools and are held in position with one cover screw (Fig. 5). The front threading portion of the cartridge, which engages the mechanism, is common to all models.

Lowering the tape from its protective channel into the tape handling path of the mechanism provides for precision alignment and driving the tape within the mechanism while playing or recording. By this design the nylon tape lifters perform only the function of preliminary positioning and thereby eliminate misalignment through cartridge production variations.

Without altering the external dimensions of the cartridge, various combinations of discs and magazines within the body of the cartridge can be handled compatibly with the front threading design and cartridge handling mech-

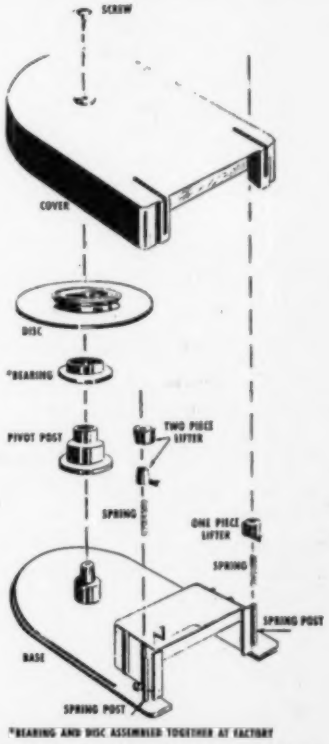


FIG. 5. Echo-Matic Cartridge Assembly (without magazine cover on disc).

[2] "New Tape Cartridge Developed," *Hi-Fi Tape Recording*, 4, No. 4, 26-27 (1957).

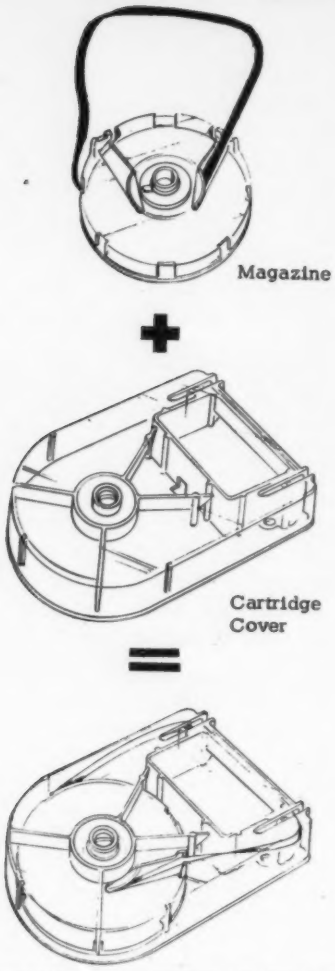


FIG. 6. Cartridge, illustrating magazine insert principle.

anisms. For example, the cartridges presently in production provide for a continuous loop and disc arrangement held in position by means of ribs molded in the plastic cover. When it is desirable to remove the loop from the cartridge for recording purposes, this loop-disc arrangement can be provided with a protective cover to form a removable magazine (Fig. 6).

By eliminating the cover ribs, room is provided for two discs mounted coaxially with the tape driven in either direction from one disc to the other. This arrangement would provide for immediate reversing on a machine designed for that purpose, such as dictating equipment.

For optimum performance of the continuous loop the tape mass should operate in a position to take advantage of gravitational force working downward against a revolving disc.

A "Topsy-Turvy" insert design utilizing two discs has been developed to operate in any position. This has certain operational advantages in applications where the tape must operate in any position, such as aircraft, pocket recorders, etc.

High-heat styrene used in production of present cartridge models provides ample stability and strength to meet handling requirements. While in operation the disc and tape must move freely. This factor would allow the tape mass to rotate during handling or shipping and cause the tape to foul. Exhaustive shipping tests have established the necessity for locking both the tape mass and disc to eliminate this problem.

A flat, light-weight phosphor bronze spring leading radially from the center bearing and pressing downward to lock the tape and disc together, provides an adequate solution. Unlocking is automatically achieved in the mechanism (Fig. 7).

TAPE FOR USE IN A CONTINUOUS LOOP

Standard magnetic tape, that meets all requirements for conventional use, is unsatisfactory for use in continuous loop operation. In the early stages of our research attempts were made to overcome this problem by mechanical designs and drive assistance for the continuous loop. While small tape loads of fifty feet or less were found feasible, larger tape loads were unsatisfactory for commercial use. Large loops soon developed heavy and erratic feed tension and ultimately bound-up.

Research into tape properties revealed two major factors contributing to malfunction in large tape footage loads. One contributing factor is the coefficient of static and kinetic friction of one tape strand against another. This movement of one tape against another is characteristic of continuous loop operation and is covered earlier in this paper under "Principles of Continuous Loop Operation." If the coefficient of kinetic friction is high the feed tension will be correspondingly high. Another important factor in loop operation is that of static charge accumulation between tape layers. When there is electrostatic attraction the normal

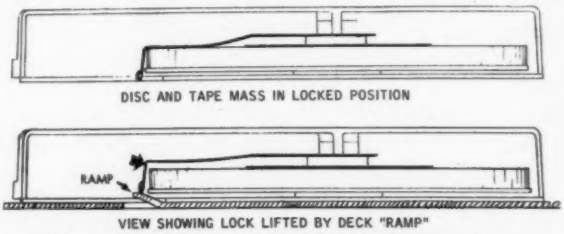


FIG. 7. Method used to lock the tape and disc together.

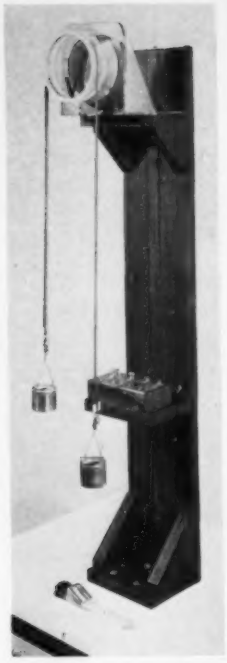


FIG. 8. Apparatus for tape friction measurement.

force between adjacent tape strands increases, thereby increasing frictional drag.

New equipment and techniques were developed to measure these two most important properties of magnetic tape loops. The apparatus for measurement of coefficient of kinetic friction consists essentially of a guide channel on a 2 inch radius (Fig. 8). One tape sample, 10 in. long, is fastened in the guide channel with oxide surface down; another sample, 36 in. long, is placed over the first sample in the guide channel, also with oxide surface down. Scale pans are attached to each end of the 36-in. sample. A 10-gram weight is placed in one pan and weights are added to the other until motion just impends upon overcoming static friction. The coefficient of kinetic friction may now be computed:

$$f_K = (1/\pi) \ln (W_2/W_1); W_2 > W_1$$

Static charge accumulation between adjacent tape strands is the second major factor for which a measurement technique was developed. Surface resistivity is a measure of the tendency for static charge to accumulate. To determine resistivity of a tape, two spring loaded metal fingers, spaced one in. apart, contact the tape placed in a guide slot. An ohmmeter is connected to these two fingers in order to read the tape resistivity between the two fixed contacts.

From the use of these devices it was determined that magnetic tape, to fill the requirements of continuous loop operation, must have a low coefficient of kinetic friction and a conductive surface in order to prevent static accumulation. This led to a search for a lubricant having properties to produce the following results on tape:

1. Reduced coefficient of kinetic friction;
2. Low surface resistivity;
3. Good adhesion; and
4. Coating thickness that would not impair high frequency response.

Colloidal graphite, properly dispersed in a suitable carrier and properly applied, was developed to meet the above requirements.[3] It is important that the graphite be colloidal since the particles will remain elemental without flocculating. The small particle size of colloidal graphite (0.5 to 1 micron) makes possible good adhesion without a binder because the particles are not mobile on the surface of the tape. The small particle size provides a thin film with good lubrication and low resistivity. Also, the high-frequency response is not impaired due to coating thickness.

TESTING PERFORMANCE OF COMMERCIAL UNITS

To determine the commercial reliability of continuous tape loop samples, and the design efficiency of devices to handle the loops, a special machine was devised (Fig. 9). This Accelerated Operational Life Tester drives magazines at a tape velocity of 80 ips, which is about ten times that of normal operation. Many magazines have accumulated 200 hours of continuous operation on the Operational Tester, which is approximately the equivalent of 2000 hours under normal operation at 7½ ips.

This Operational Tester is also used to check lubrication formulae on tape under operating conditions. The standard load for operational tests consists of 180 feet of tape with the proper loop size. The tape samples are loaded in the magazine and placed on the Operational Tester to run 24 hours a day. Operational performance records on each unit tested include: (a) ease of starting, (b) "jam-ups," (c) binding, (d) tape breakage, or any other abnormal condition.

A tape sample is considered to be at the end of its operational life when it has more than 5 jam-ups or tape breaks in a one-hour period and runs erratically. For a comparison of the physical and operational properties of lubricated and unlubricated tape see Table I which is a typical performance record report.

It can be seen from the data that the unlubricated sample

3. Cousino, Bernard A., U. S. Pat. No. 2,804,401, Filing Date, April 11, 1955; Date of Issue, Aug. 27, 1957; "Method for Applying A Graphite Lubricant Or The Like To the Tape."

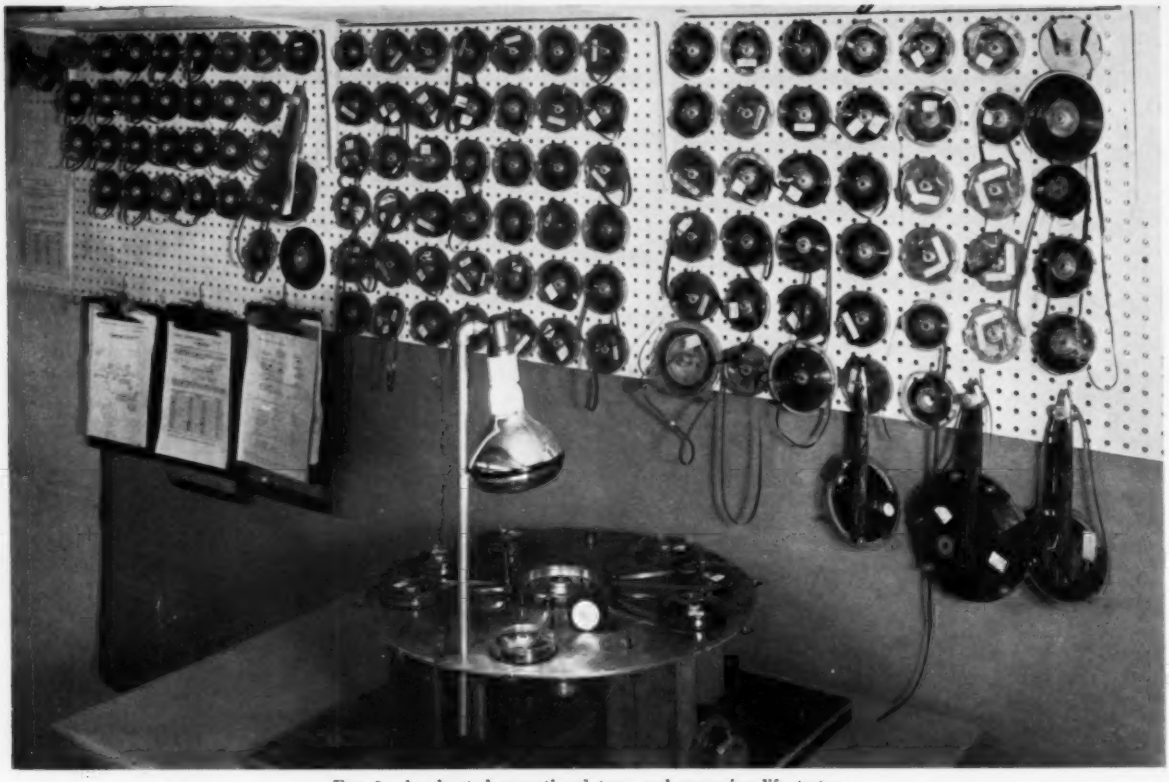


FIG. 9. Accelerated operational tape and magazine life tester.

ran only 44 hours before total breakdown; operation was unstable, resulting in wide variation of feed tension. This unstable operation can be attributed to the high coefficient of friction and essentially infinite resistivity. In comparison, the lubricated sample had no jam-ups or tape breaks, and the operation was stable. The lubricated sample had a lower coefficient of friction, decreased resistivity, and smoother starting. In contrast, the unlubricated sample started with extreme difficulty and ran erratically throughout the test.

In connection with the operational tests, lubricated high-heat tapes were found to operate satisfactorily at temperatures of 180°F. produced by an infra-red heat lamp (Fig. 9).

MEASURE OF ELECTRONIC PERFORMANCE

Under normal operating conditions for both the magazine and cartridge, flutter and wow of from 0.25% to 0.30% rms have been measured. Measurements of magazines operated on standard reel machines show no difference in flutter and wow characteristics when compared to reel operation on the same machines.

The high-frequency loss due to lubricating coating thickness must be measured when the oxide side is coated, as in Möbius-loop operation where the tape is double oxide coated. By splicing the tape with a half twist in the loop, both sides of the tape are utilized. To avoid "bleed-

TABLE I. Comparison of Physical and Operational Properties of Lubricated and Unlubricated Tape Samples.

	Operational Results			Physical Measurements			
				Coefficient of Kinetic Friction		Resistivity, Megohms	
Tape Sample	Hours Run	Tape Breaks and/or Jam-Ups	Observations of Performance	Prior to Run	After Running	Prior to Run	After Running
Unlubricated	44	8 jam-ups	Extremely difficult to start; tape motion unstable	0.64	0.63	<1000	<1000
Lubricated, ff #108	200 (still running)	None	Smooth starting stable operation	0.44	0.55	3	.02

through" this operation is only usable with half-track heads. The high-frequency loss due to lubricating coating thickness is determined by taking a tape sample and lubricating only half of the total sample, with the other half remaining uncoated. These two samples are spliced together and placed on a professional recorder. A high-frequency tone with a wave length of 0.5 mil is recorded. The two samples are played back to determine any difference in level between the two samples. It has been found that the coating thickness loss is less than ¼ db at 15 kc, at a speed of 7.5 ips.

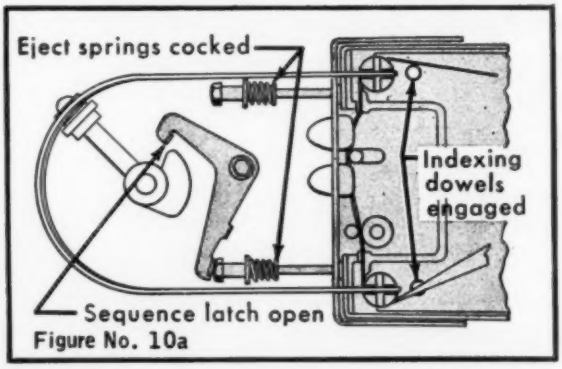
MECHANISM DESIGNS FOR CARTRIDGE OPERATION

The basic cartridge design was conceived to allow wide flexibility in mechanisms designed for various applications and for various price levels. To realize better the need for this flexibility, consider the following partial list of potential applications:

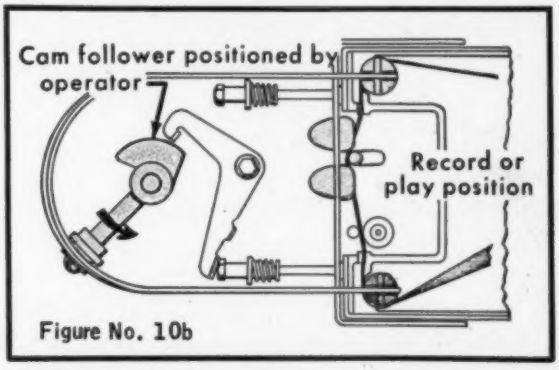
1. Automobile dashboard recorders
2. Record and announce systems for buses, trains, airplanes and boats
3. Automatic telephone devices
4. Point-of-purchase message repeaters
5. Background music systems
6. Home market for music and education
7. Automatic broadcasting and multiplexing
8. Juke box play and duplicating machines
9. Slide and filmstrip synchronization with sound
10. Education on all levels
11. Dictating machines
12. Sleep learning and psychology
13. Pocket recorders
14. Rocket and guided missile research
15. Automation and telemetering controls

Some of the applications in the above list are open to the tape recorder industry only through the use of a self threading continuous play cartridge principle: message repeaters, for example.

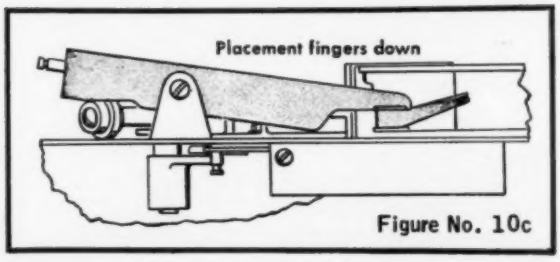
Many of the above applications call for multiple storage and automatic handling of tape cartridges (the juke box, for example) and therefore these factors were taken into consideration in the development of both the cartridge and



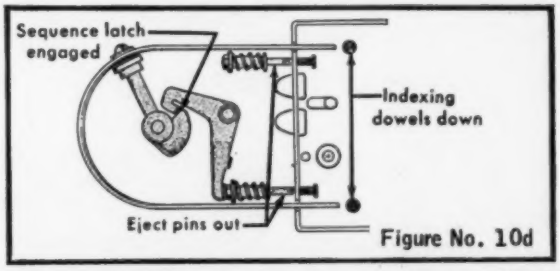
CARTRIDGE in inserted position. Indexing dowels are engaged, eject pins cocked, sequence latch open and play circuit triggered for operation.



PLACEMENT FINGERS are down holding tape loop-spring mechanism against recording head. Action continues until automatic ejection by electronic circuit or until stopped by operator.



SIDE VIEW at play or recording condition shows cam and cam follower holding placement fingers against tape springs and tape. Cam follower rides firmly in cam recess until retracted by movement of control knob.



EJECT CONDITION shows cartridge removed, cam and follower in neutral position, eject pins out, dowels in up-position awaiting next cartridge. Recording mechanism, therefore, is always in one of four conditions: cartridge in or out; unit on or off.

FIG. 10. Schematic diagrams of cartridge and its handling mechanism: (a) cartridge "in", (b) and (c) "record" or "play" position, (d) cartridge out.

the mechanism. For either automatic handling or manual placement of the cartridge, two index holes have been provided in the front base.

Cartridge handling mechanisms now in production or development have taken several different forms or combinations. The original mechanism[4] developed for patent and testing purposes is illustrated in Figs. 4 and 11. This represents the "push-in" design in which pushing the cartridge into the slot overrides the indexing dowel (C, Fig. 4) pins until they drop into cartridge index holes, to hold the cartridge in place. This action spring-loads the ejection pins, unlocks a sequence latch to permit dial control operation (Fig. 10a), and lowers the tape from its protected channel, bringing the capstan-idler and tape guides forward into "play position" (Fig. 10b). A turn of the dial control knob reverses the procedure and automatically ejects the cartridge (Fig. 10d).

Another version of the "push-in" design eliminates the dial control and accomplishes all of the above operations by means of the push-pull force upon the cartridge itself.

Another design now in production uses the "drop-on" principle. This operates by dropping the cartridge onto two fixed index dowels and lowering the tape strand into position by means of placement fingers on a hinged cover. Pressing the cover into place also releases the capstan-idler and tape guides. This design may be incorporated into standard reel-to-reel machines for dual function as a cartridge and standard reel recorder.

Once the tape has been lowered from its protective channel as described in the above designs (Fig. 10c), many combinations of heads, capstan-idlers, guides or pressure pads, that are already well established in the art, can be used. The greatest flexibility in head sizes, mounting, and adjustment, can be achieved by placement of the magnetic heads to the outside front of the cartridge (Fig. 6). The heads need not fit under the cartridge brow. The capstan-idler, and guides or pressure pads with the above head placement are mounted to the inside of the cartridge throat.

When the guides are used to bring the tape forward to conform to outside head configurations during "play," it is important that the capstan-idler should disengage the tape last when the mechanism disengages the tape for "stop." This provides a straightening action on the exposed tape strand to insure its positive return into the cartridge channel. Designs operating with the tape relatively in line with the protective tape channel of the cartridge do not require the above straightening action.

The mechanism design includes a "lock-lift" for unlocking the tape mass and disc lock arm. This takes the form of a "step" for the "drop-on" design or a "ramp" for the "push-in" design (Fig. 7).

FIG. 11. Original development model.

Discussion

Q. What goes on when you put the cartridge in the machine? It looks as if the tape came out of the upper level, and in some way was pulled down, came over the heads, and was drawn down to where the pinch roller could get it.

A. You are correct. That is exactly what happens. The tape is brought downward in front of the head, and then as the sequential movement of the lever goes forward the tape is engaged by guides, and brought into contact with these roller heads.

Q. Regarding the standard unit that you have just shown us, how do you know when the tape is in proper condition to start by looking at it? That is, assume that you have taken the tape out of the machine in the middle of a playing sequence as you did, and then you put it down with some other tapes and pick it up again. Is there any way of knowing whether the tape has been half run through or not?

A. Yes. For example, with the use of a white or colored leader spliced into the loop itself, and an index on the cover, you can look down and see whether you are in the middle of the play or not. However, this is a solution that some applications do not require since the unit can be made to shut off automatically by means of a tone or a sound which actuates a relay. But you are absolutely right if the unit is interrupted in the middle, it can be—you will find that you are in the

[4] "Single Plastic Cartridge Automates Tape Insertion," *Design News*, 11, No. 6, 22-23 (Mar. 15, 1956).

center of the selection. However, one thing that evolved in our development work on the breakdown machine that you saw demonstrated: in running the tapes 80 in. per second we assumed at first that this was a ten-to-one breakdown or better. It turned out the other way. Running the tapes at high speeds was less of a breakdown test than running it at normal speed, because if you study it for a moment you will see that the centrifugal force is in favor of the continuous loop. It allows the innermost strand to come out a little easier because it relieves the pressure at the center cone.

Q. I think you have almost answered my next question which is how fast can you make this thing run.

A. Very frankly, we do all our breakdowns at 80 in. per second. We have found that quite satisfactory, and we have not made any exhaustive breakdown tests as to where the point of diminishing returns may be, but it appears that the loop is compatible with high speed work.

Q. Is there any mechanism similar to this that can be reversed?

A. Well, in a problem with any continuous loop you would have to repeal the laws of physics before you could back up a continuous loop. However, we have attempted to bring about some degree of compatibility in our thinking by using the same centrifugal properties, dimensions of a cartridge, and a coaxial cartridge, and this is in development. We are not in production with it, but it is a very promising compatible design, that we feel will find its place in conjunction with these plain devices; but this provides too in the mechanism for a rubber drive puck that will drive against the edge of the periphery of the lower disc.

Q. Have you done anything with this in the direction of programming relatively low speed computing operations, or control of operating tools?

A. We find this is being used by some people, but not by ourselves. We find a considerable amount of interest in applications in that field and we supplied quite a few test cartridges for that. In the automatic telephone answering systems too, it is quite extensively used.

Q. Are you intending to develop any ruggedized or instrumentation version of this machine or cartridge?

A. We have done some preliminary testing on that, and at the moment, it is not our major objective, however. We have two companies that are asking us to enter some subcontract work in this field, and we are interested but have not done much with it as yet.

THE AUTHORS

Bernard A. Cousino attended Columbia University from 1923 through 1926. He received a Bachelor of Science degree from the University of Toledo. After graduation he served in the department of education of the National Council, Boy Scouts of America, and as Director of Education of the Sylvania, Ohio school system. He founded Cousino, Inc., of which he is president, in 1936. He is a charter member and past president of the National Audio-Visual Association.

Ralph Cousino attended the University of Toledo, from which he received his Bachelor of Science degree in electrical engineering. He subsequently taught at the University of Toledo Communications Department. He served the United States Army Signal Corps as an electronics engineer, at the Signal Corps Pictorial Center, Astoria, Long Island. In this capacity, Mr. Cousino was engaged in the development and quality control of optical, disc, and magnetic recording systems. He was awarded the Certificate of Achievement for his efforts. In his present position as Chief Engineer for Cousino, Inc., he is engaged in development and research work on continuous magnetic tape devices.

Some Observations on Reproduced Sound in an Automobile*

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Some of the physical and psychological factors of reproduced sound in an automobile are discussed. The environmental conditions, such as: ambient noise as it affects audible frequency and dynamic range, "listening room" size, audience seating arrangement, and acoustical properties, are compared with these conditions in a living room or concert hall. The transducer efficiency, size, loading, required power handling, frequency balance, frequency and dynamic range, and the effects of its location on the distribution and delivery to the listeners are considered. Psychological factors affecting the desirability of many experimental loudspeaker locations tested are presented.

INTRODUCTION

SINCE ITS INTRODUCTION about 28 years ago, the automobile radio has become a major part of the commercial radio receiver industry and provides perhaps the largest audience for AM broadcasting. As a result of this commercial importance, the design specifications of a quality automobile radio are carefully established. The major performance consideration is the effective reproduction of the sound under the conditions in the automobile. Although work has been done with tape and disc record players in an automobile, most experience has been with the radio.

This discussion concerns the factors affecting the delivery and quality of the sound reaching the listener and interpreted by him.

Let us consider: the environmental conditions affecting the system; the system itself, and the effects of both the environment and the system on the listener.

ENVIRONMENTAL CONDITIONS

Those of interest here are: (a) the ambient noises and (b) the properties of the "listening room"; its size, seating arrangement and acoustical properties.

Ambient Noise

The ambient noise is comprised of the usual traffic and other acoustical disturbances external to the automobile and the noises of the automobile itself, principally due to wind, road and engine. In this connection, it is interesting to note that, contrary to public concept, the wind noise heard by the listener has become greater by streamlining. Now, instead of the bow wave breaking some distance away, the turbulence is in the slipstream hugging the car and, consequently, close to the ears of the occupants. Much of the road and tire noise is transmitted up through the floor of the car, as shown by studies of Dr. Harry F. Olson and others.

Surveys indicate that the ambient noise level in the average home is about 43 db.[1] In an automobile with the windows open, traveling at a speed of 65 mph, we found the average ambient noise to be approximately 102 db. With this level as a base and the upper level restricted to a value comfortably below the threshold of pain, which is about 120 db, the dynamic range of the reproduced sound then is correspondingly lessened. These conditions are shown in Figs. 1 and 2.

Fig. 1 shows the noise spectrum in an automobile parked and also when traveling 65 mph, with the windows open and closed, compared to the noise spectrum in a home. Notice that the level of the lower octaves is approximately 50 db greater in a moving automobile. When the automobile windows are open the noise level increases across the entire band, but to a slightly greater degree in the higher octaves, as shown. This increase, of course, is due to airborne noises, principally the wind. The masking effects of the various noise spectra shown in the next figure were obtained from data of Fletcher and Munson.[2]

* Paper delivered by Mr. D. E. Brinkerhoff at the Ninth Annual Convention of the Audio Engineering Society, New York, October 12, 1957. Manuscript received October 7, 1957.

† Technical Assistant to the General Manager.

‡ Head, Acoustical Engineering Laboratory.

[1] H. F. Hoth, "Room Noise Spectra at Subscribers Telephone Locations," *B.S.T.J.* (April 1941) p. 499.

[2] H. Fletcher and W. A. Munson, "Relations Between Loudness and Masking," *J. Acous. Soc. Am.*, **9**, 1 (1937).

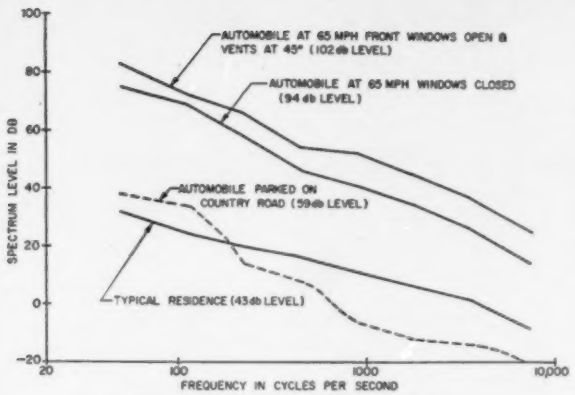

AUTOMOBILE AT 65 MPH FRONT WINDOWS OPEN & VENTS AT 45° (102 db LEVEL)
AUTOMOBILE AT 65 MPH WINDOWS CLOSED (94 db LEVEL)
AUTOMOBILE PARKED ON COUNTRY ROAD (59 db LEVEL)
TYPICAL RESIDENCE (43 db LEVEL)
SPECTRUM LEVEL IN DB
FREQUENCY IN CYCLES PER SECOND

FIG. 1. Comparison of noise spectra.

Fig. 2 shows the effect of the spectra on the threshold of hearing. The latter is approximately 50 db higher in the automobile than in the home in the 100 cps region and 35 db higher in the 10,000 cps region. The maximum rms response of a 75-piece, live orchestra at levels of 94 and 65 db are also shown.[3,4] Our tests show that 94 db is the average level a listener selects in the presence of the most severe masking noise in an automobile. Although not shown, with the windows closed, this average level is 88 db. Other studies indicate that 65 db is the preferred listening level in the home.[5] Thus, the automobile listening level under the most severe conditions is about 29 db higher.

The crosshatched areas shown between the curves for the live orchestra response and that for the masking level, represent the audible range for each set of conditions. The two vertical-dashed lines point out the extremities of low frequency audibility for the two listening environments. Note, in the home, with the masking noise levels shown, the low frequency audible limit is 70 cps and in the automobile 160 cps, due in the latter case to low-frequency road rumble and wind noise. The high frequency response is similarly masked by noise in this range, principally due to electrical interference through the radio, in low signal level areas. For this reason, and because the balance of highs-to-lows must be satisfactory, the typical automobile radio has a high frequency roll-off beginning at about 5,000 cps, as shown by the dashed line on the 94 db level.

The high listening level required means high undistorted power output from the electrical system and/or the loudspeaker in the automobile. Electrical power output is expensive. Much of the increased power output needed can be obtained at less cost acoustically, that is, by the use of a more nearly optimum design loudspeaker, better baffling and location and a grille with minimum restriction. Thus, more power is obtained, preserved, and delivered to the listeners' ears. These factors will be discussed later.

Several approaches, other than that of more power, have been tested to solve the problem due to ambient noise. Improved sound treatments of the automobile body to keep out noise are constantly being developed, then tested by the Noise and Vibration Laboratory of the General Motors Proving Grounds,[6] and introduced. These, of course, do not reduce the noise which comes in through open windows. Volume companders, to automatically limit the dynamic range of the reproducer output, have been developed and tested. However, they introduce distortion, reduce realism and are costly. A system wherein the volume was changed automatically with car speed change was developed and used in General Motors cars as early as 1938 but the improvement was not considered by the consumer to be worth the complication and cost.

Properties of the Car Interior

Then there is the group of environmental conditions due to the seating arrangement, size, and acoustics of the "living room." We are in the enviable position of selling the living room with the sound reproducing system (or *vice versa*), so that the designer knows, in advance, the influencing factors. The smaller volume of the car interior works to our advantage in obtaining the 29 db power increase required at the listeners' ears. On the other hand, the distribution problem is more severe since one listener may be

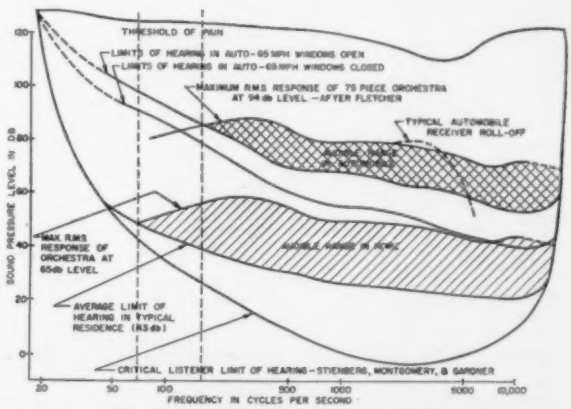

THRESHOLD OF PAIN
LIMITS OF HEARING IN AUTO - 65 MPH WINDOWS OPEN
LIMITS OF HEARING IN AUTO - 65 MPH WINDOWS CLOSED
MAXIMUM R.M.S. RESPONSE OF 75 PIECE ORCHESTRA AT 94 db LEVEL - AFTER FLETCHER
TYPICAL AUTOMOBILE RECEIVER ROLL-OFF
MAX. R.M.S. RESPONSE OF ORCHESTRA AT 65 db LEVEL
AVERAGE LIMIT OF HEARING IN TYPICAL RESIDENCE (43 db)
CRITICAL LISTENER LIMIT OF HEARING - STEINBERG, MONTGOMERY, & GARDNER
SOUND PRESSURE LEVEL IN DB
FREQUENCY IN CYCLES PER SECOND

FIG. 2. Limits of hearing in automobile and living room.

[3] L. J. Sivian, H. K. Dunn, and S. D. White, "Absolute Amplitudes and Spectra of Musical Instruments and Orchestras," *J. Acous. Soc. Am.*, **2**, 330 (1931).

[4] Harvey Fletcher, "Hearing, The Determining Factor for High-Fidelity Transmission," *Proc. IRE*, **30**, 266 (1942).

[5] H. A. Chinn and P. Eisenberg, "The Tonal-Range and Sound Intensity Preferences of Broadcast Listeners," *Proc. IRE*, **33**, 571 (1945), **34**, 757 (1946).

[6] D. C. Apps, "The Use of Binaural Tape Recording in Automobile Noise Problems," *J. Acous. Soc. Am.*, **24**, 660 (1952).

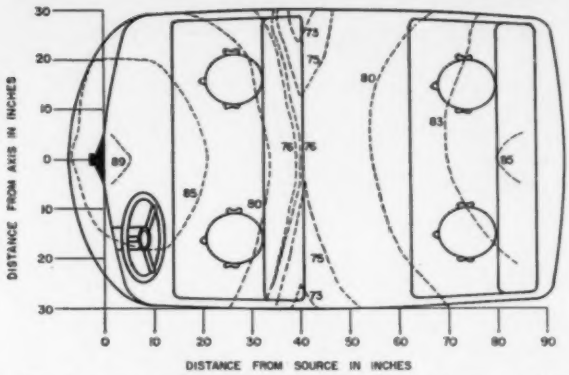


FIG. 3. Sound level contours in automobile at 80 cps: 6" × 9" speaker, 0.5 v on the voice coil.

a foot or less from the sound source and another, six feet or more from it.

The size of the car body is such that fundamental modes of vibration occur at approximately 70 and 110 cps. The top zone is surrounded mostly by glass with a sound absorption coefficient of 0.02. A loudspeaker here is close to the ears of the listeners. Standing waves are produced here with intensity variations from peak to null in the order of 10 db. This is particularly true of hard-top models. The reverberation time remains relatively short, however, because of the small volume of the interior. In the floor zone the carpeting and upholstery have high sound absorption with a coefficient of 0.75 and a loudspeaker here is farthest from the listeners' ears.

Fig. 3 shows a plot of the sound pressure contours inside an automobile of an 80 cps signal from a front location loudspeaker, as shown. The sound pressure decreases as we move from the source back to a point approximately in the middle of the interior and then increases as we approach the rear glass, to a level almost equal to that near the source. The sound level near this mode of vibration is more intense for rear seat listeners than for front seat listeners by about 3 db.

Fig. 4 shows a plot of the sound pressure contours of a 400 cps signal. This illustrates the narrower directional pattern characteristics with the decreased ratio of the wave length-to-source diameter. The extreme variations of sound pressure with position indicate one of the reasons sound pressure measurements made in an automobile with the microphone at passengers' ear positions are difficult to duplicate and all but impossible to evaluate.

Fig. 5 shows a plot of the sound level through the axis of the automobile with data taken from Figs. 3 and 4. The level of the 400 cps signal rises and falls approximately every 20 inches but the average level decreases as a function of distance to a point approximately 70 inches from the source. Thus, the frequency balance is tilted toward the bass end and the loudness is reduced for the rear seat listeners. A listener located on the axis and close to the loudspeaker receives the maximum treble response and loudness. This agrees with the subjective observations that the front seat listener enjoys the more complete range and, therefore, better intelligibility. The frequency range and loudness received by the rear seat listener is satisfactory for less attentive listening.

TRANSDUCER AND LOADING REQUIREMENTS

As in all sound systems, it is important to have balance as well as frequency range and these are altered by the environmental conditions. The basic requirement for the audible frequency range is that which is necessary for speech intelligibility.[7] With just this, however, the tone is hard and irritating. Much has been published on the frequency range preferences of listeners.[5,8] Due to the high volume level required and the close spacing between source and listener in an automobile, a smooth frequency response characteristic is of utmost importance to prevent auditory fatigue and distraction.

As mentioned earlier, the loudspeaker for an automobile must have high power output and efficiency. The latter, overall, is comprised of the efficiencies of the electrical to mechanical, and the mechanical to acoustical, transfers of energy. The first of these is largely determined by the characteristics of the loudspeaker motor. The second is determined by the effective loading of the diaphragm and the combination of diaphragm area and excursion. Of the

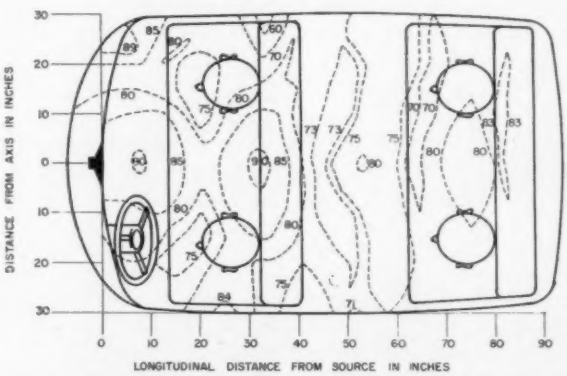


FIG. 4. Sound level contours in automobile at 400 cps: 6" × 9" speaker, 0.5 v on the voice coil.

[7] L. L. Beranek, "The Design of Speech Communication Systems," *Proc. IRE*, **35**, 880 (1947).

[8] H. F. Olson, "Frequency Range Preferences of Speech and Music," *J. Acous. Soc. Am.*, **19**, 549 (1947).

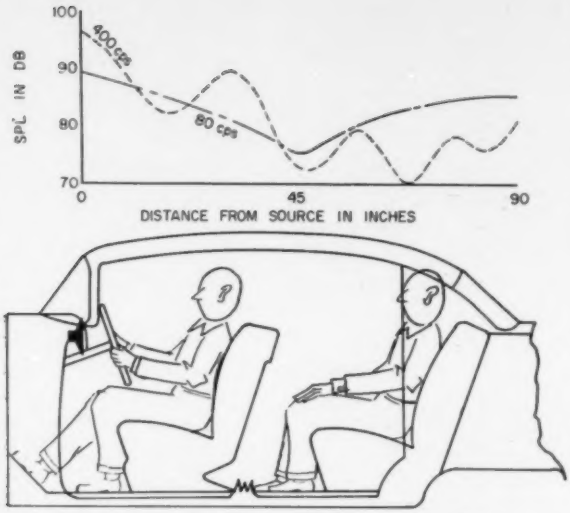


FIG. 5. Sound level through axis of automobile.

latter, the one extreme is a diaphragm of large area but small excursion as characterized by the electrostatic type. Since such a configuration could be accommodated in an automobile, Delco Radio initiated the revival of this type just after World War II. Later, however, our project was shelved despite considerable progress and after much effort and money expenditure because of inadequate bass response and unsatisfactory life, particularly out-of-doors, even with improved dielectric materials. Work on this type was continued by others, resulting in the present tweeters for home use. The other extreme is a small area, large excursion cone diaphragm dynamic loudspeaker (Fig. 6) with increased driving power which, in turn, increases the volume current in the acoustical power equation:

$$P_a = u^2 R_r$$

where P_a = acoustical power, u = volume current, and R_r = radiation resistance.

With the larger excursion, it is difficult to avoid nonlinearity of the moving system which increases the harmonic and intermodulation distortions. Thus, the optimum diaphragm area and excursion for this service are about those of the usual, larger automobile loudspeaker. Since the mounting space for the loudspeaker diaphragm is almost always rectangular, Delco Radio initiated the development of the elliptical dynamic loudspeaker and introduced it in the automobile about 20 years ago. It is now the type most often used.

The best baffle possibilities available in an automobile are the package shelf back of the rear seat, and the instrument panel. The average loudspeaker location on the latter has the shortest baffle leakage path, of the order of one foot or approximately $\lambda/15$ at 80 cps. This can be offset by arrangements discussed later.

The grille in front of the loudspeaker cone should exhibit a large percentage opening uniformly distributed over the entire area of the cone. Severe tonal and efficiency impairment result if an appreciable part of the cone is masked off or if the masking is asymmetrical. The resulting response is rough and ragged, especially in the middle- and high-frequency ranges, and sounds restricted and unnatural.

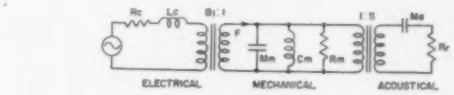
An appreciable cavity between the cone and grille, particularly with bunched or inadequate opening in the latter, reduces efficiency and muffles the response. The cavity compliance, combined with the acoustic mass of the air in the grille openings, forms an acoustic low-pass filter. Cavity resonances also produce coloration and poor transient response.

LOUDSPEAKER LOCATION

As indicated earlier, the loudspeaker location is the most important factor in the effective delivery of the acoustical power to the ears of the listeners. Efficient delivery, equal distribution, tonal characteristics and car styling are the determining factors.

Coupling Efficiency

The efficiency of the loudspeaker can be increased greatly by locating it so that advantage is taken of the natural contours of the automobile to improve the coupling between the loudspeaker and the interior. First, the location should be a high pressure point for most modes of vibration of the interior, throughout the audio range. Also, it is sometimes possible to locate the loudspeaker so that a semi-horn loading is achieved, thus improving the impedance match between the cone and the medium. A good example is the top instrument panel position where the front side of the



$F = Bli$

WHERE F = MECHANICAL FORCE IN DYNES
B = FLUX DENSITY IN THE AIR GAP IN GAUSS
l = LENGTH OF THE VOICE COIL CONDUCTOR IN CM.
i = CURRENT IN THE CONDUCTOR IN AMPERES

$P = Fsv = EI$
MECH. ELECTRICAL

$Pa = u^2 Rr$

WHERE Pa = ACOUSTICAL POWER
u = VOLUME CURRENT
Rr = RADIATION RESISTANCE

$$Rr = \pi R^2 \rho c \left[1 - \frac{J_1 2kR}{kR}\right]$$

WHERE R = RADIUS OF PISTON
$k = 2\pi/\lambda$
ρ = DENSITY OF MEDIUM
c = VELOCITY OF SOUND
J_1 = BESSEL FUNCTION OF THE FIRST ORDER

FIG. 6. Analogous circuit for direct-radiator loudspeaker.

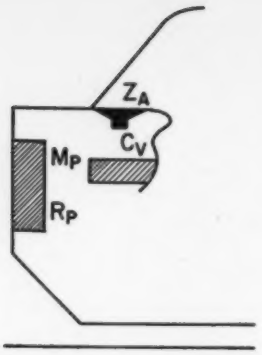


FIG. 7. Loudspeaker loading in automobile instrument panel.

cone is loaded by the horn formed by the windshield and instrument panel (Fig. 7). This position increases the efficiency as much as 6 db more than if the loudspeaker is located in the front elevation of the instrument panel.

It is also possible to couple the back of the loudspeaker cone to the interior for improved low frequency response. The instrument panel can provide a bass reflex cavity with a loaded port. The resonance of the cavity formed by the instrument panel, cowl, engine bulkhead, side kick pads and floor is about 85 cps for the entire system, but this resonance rises to as much as 120 cps when the top, sides and complete floor and back of the automobile body are not included in a mock-up dummy.

The familiar rear loudspeaker location on the package shelf back of the rear seat takes advantage of the huge rear cavity provided by the luggage compartment which greatly improves its low frequency efficiency. Cavity resonances sometimes produce prominent middle bass frequency peaks, however. The efficiency of delivery to the driver of the car (and there is always a driver), of the middle and high frequency ranges needed for intelligibility, is thereby reduced.

Fig. 8 shows the location of 20 loudspeakers in an automobile which were tested singly and in combinations. Measurements were not completely repeatable and do not include important psychological factors. Hence, they were useful as guides only and the final evaluations were made by subjective listening. The locations were divided into three vertical zones:

The Floor Zone—This, of course, is farthest from the listeners' ears and much of the loudspeaker energy goes into the carpeting, upholstery, and passengers' clothing. Therefore, the efficiency, sound delivery and distribution uniformity are poor. In addition, there is usually insufficient room for adequate baffling and there are problems of dust, dirt and mud.

The Top Zone—This is closest to the listeners' ears but then the distribution uniformity is poor since the loudspeaker may be but a few inches from one listener's ear and six feet or more from the ears of another. Also, because present-day automobile bodies are low and trim, there is insufficient room for a suitable rear cavity.

Although multiple speakers in this zone, one next to the ear of each listener, (positions 11, 13, 16 and 18) provide maximum signal-to-noise ratio, approaching that of headphones, the result is too intrusive, particularly for the driver. Moreover, if a loudspeaker is not centered with respect to both ears of the listener, there is an instinctive mental effort to adjust the balance, which results in fatigue. The amazing ability of our binaural hearing system, to locate and "unmask" the faint signals we wish to hear while ignoring other sounds from other directions, is impaired. Therefore, loudspeakers in the top zone particularly, should be located at the front or in back. The preference between the two is determined by the degree of attentive or inattentive listening desired. For attentive listening, the source of the sound should be in front to avoid the urge to turn and face the source.

The Mid-zone—This is the most satisfactory. Loudspeakers located here provide the most desired degree of attentive/inattentive listening, the best distribution uniformity, and good signal-to-noise ratio. In this zone also, best baffling and rear cavity possibilities are afforded.

It has become quite common to have at least two loud-

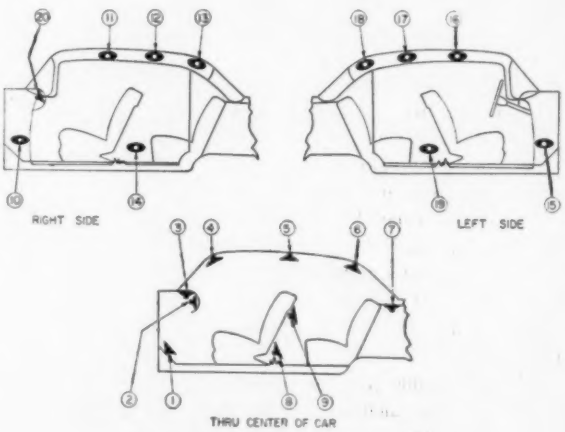


FIG. 8. Loudspeaker location study.

speakers in an automobile, usually one in front and one in the rear. An extension of this arrangement is four mid-zone loudspeakers, one in each corner of the interior. Such combinations provide excellent sound delivery and good distribution uniformity. There is a pleasant suggestion of stereo on full orchestra but some confusion and slight reduction in intelligibility on single voice or instrument. In the case of the solo voice, the improvement here in delivery efficiency with multiple sources is lessened, particularly when laterally separated, by the reduction in the ability of our binaural hearing system to discriminate between the wanted and unwanted sounds. Since the rear loudspeaker response is different from that of the one in front because of the luggage compartment cavity, a semi-divided-range multiple-unit system results. More completely divided-range, multiple-unit systems also have been used to reduce intermodulation distortion. This technique is unnecessary for the frequency range required and such a system, if the "woofer" and "tweeter" are physically separated, can be made satisfactory for only one or two listeners. The interesting possibility of a response time delay between divided-range separated loudspeakers, to produce the subjective effect of a single source, is likewise effective only for one or two listeners in an automobile.

In multiple loudspeaker systems it is usual, as we have stated, to have the rear unit in the package shelf behind the rear seat rather close to the ears of the listeners there. A variable fader control is frequently provided to adjust for this. Even without such a control, the advantages of this present arrangement outweigh the variation in distribution.

SUMMARY

We have endeavored to present not only the severe problems of the environment in an automobile but also evidence that psychological influences are as important as the physical ones. These are compensated for by the fact that we have a fixed audience and a known and reproducible "listening room." Therefore, these predictable conditions can be taken into consideration in the overall system design, which is usually the case with automobile radios. The end result has been a very acceptable product, so much so, that it is frequently reported that high quality automobile radios are preferred to the usual home radios. Furthermore, instead of its being a distraction to the driver, the radio continues to be an aid in lessening his fatigue, in increasing his alertness, and in making him less anxious to hasten to his destination.

THE AUTHORS

Mr. Bertram A. Schwarz is Technical Assistant to the General Manager at the Delco Radio Division, General Motors Corporation in Kokomo, Indiana.

Before joining General Motors, Mr. Schwarz served for two years as chief engineer of the Automobile Radio Division of the Zenith Radio Corp., and for five years as Vice President in charge of engineering for Consolidated Industries, Ltd., Toronto. His developmental work has brought him thirty patents in the fields of radio, electronics, tuning systems and loudspeakers.

Projects now carried on under Mr. Schwarz's supervision include loudspeakers; transistors and other semiconductors; radar and counter-radar; military electronics and communications.

He has been a Fellow of the Institute of Radio Engineers since 1955, and is active in its Professional Group on Broadcast and Television Receivers.

Donald Brinkerhoff is a graduate of Purdue University, where he earned his Bachelor of Science degree in electrical engineering in 1943. He attended the Army Officers Electronics School at Harvard University and the Massachusetts Institute of Technology Radar School. He was appointed an instructor of Electrical Communication Engineering by the M.I.T. Board of Directors in 1944. In 1945, he was assigned to the Army Ground Forces as a technical board member in charge of radar evaluation. Mr. Brinkerhoff joined Delco's Engineering Department later on that year. He was placed in charge of its Acoustical Engineering Laboratory in 1952, and is now responsible for loudspeaker and acoustical system development and design.

Mr. Brinkerhoff is an alternate member on the Committee on Electro-Acoustic Devices of the Acoustical Society of America. He also belongs to the Professional Group on Audio of the IRE.

TEST RESULTS

TESTED: for performance by Audio Instrument Company, Inc., an independent laboratory.

RESULTS: **Garrard Model 301 tested even better than most professional disc recording turntables...sets a new standard for transcription machines!**

Read Mr. LeBel's report below

3 Stock machines selected at random!

Gentlemen:

We have tested the three Garrard Model 301 Turntables which the undersigned selected at random from sealed unopened cartons in your warehouse stock. These three bore the following serial numbers: 867, 937, 3019. We used a standard Model WB-301 mounting base without modification, a Leak tone arm fitted with their LP cartridge, and a complete Leak preamplifier and power amplifier, model TL/10.

Pickup and amplifier system conformed in response to the RIAA-new AES-new NARTB curve within ± 1 db.

Standards referred to below are sections of the latest edition, National Association of Radio & Television Broadcasters Recording and Reproducing Standards. Our conclusions are as follows:

Turntable easily adjusted to exact speed!

Measurements were made in accordance with NARTB specification 1.05.01, using a stroboscope disc. In every case, speed could be adjusted to be in compliance with section 1.05, i.e. within 0.3%. In fact, it could easily be adjusted to be exactly correct.

WOW less than NARTB specifications!

Measurements were made at 33⅓ rpm in accordance with NARTB specification 1.11, which calls for not over 0.20% deviation. These values substantially agreed with those given on Garrard's individual test sheets which are included with each motor.

Garrard Serial No.	%
867	.17
937	.13
3019	.12

Rumble less than most professional recording turntables!

Measurements were made in accordance with sections 1.12 and 1.12.01, using a 10 to 250 cps band pass filter, and a VU meter for indication. Attenuation was the specified 12 db per octave above 500 cps and 6 db per octave below 10 cps. Speed was 33⅓ rpm.

Signal to Rumble Ratio Using Reference Velocity of 7 cm/sec at 500 cps

This reference velocity corresponds to the NARTB value of 1.4 cm/sec at 100 cps.

Rumble: checked by official NARTB standard method (—35 db. min.) —52 db.!

Garrard Serial No.	DB
867	52
937	49
3019	49

The results shown are all better than the 35 db broadcast reproducing turntable minimum set by NARTB section 1.12. In fact they are better than most professional disc recording turntables.

Signal to Rumble Ratio Using Reference Velocity of 20 cm/sec at 500 cps

Rumble: checked by Manufacturer A's methods —61 db.!

Garrard Serial No.	DB
867	61
937	58
3019	58

We include this second table to facilitate comparison because some turntable manufacturers have used their own non-standard reference velocity of 20 cm/sec, at an unstated frequency. If this 20 cm/sec were taken at 100 cps instead, we would add an additional 23.1 db to the figures just above. This would then show serial number 867 to be 84.1 db.

Rumble: checked by Manufacturer B's methods —84.1 db.!

It will be seen from the above that no rumble figures are meaningful unless related to the reference velocity and the reference frequency. Furthermore, as stated in NARTB specification 1.12.01, results depend on the equalizer and pickup characteristics, as well as on the turntable itself. Thus, it is further necessary to indicate, as we have done, the components used in making the test. For example, a preamplifier with extremely poor low frequency response would appear to wipe out all rumble and lead to the erroneous conclusion that the turntable is better than it actually is. One other factor to consider is the method by which the turntable is mounted when the test is made. That is why our tests were made on an ordinary mounting base available to the consumer.

Of greatest importance! Always consider these vital factors to evaluate any manufacturer's claim.

Very truly yours,

C. J. LeBel

AUDIO INSTRUMENT COMPANY, INC.

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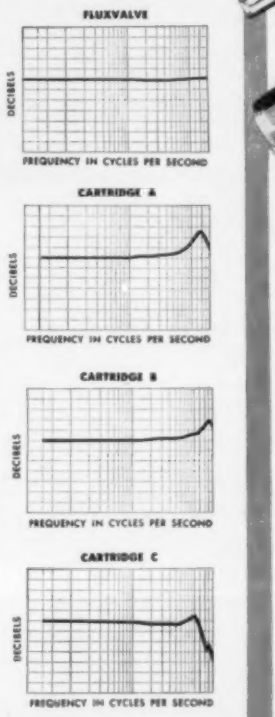
PICKERING has had long experience in the cartridge field, supplying the finest quality products for recording studios, broadcast stations, wired music services, and high fidelity home music systems. As a result of this extensive experience, PICKERING has developed the **FLUXVALVE** . . . the *one* cartridge which incorporates *all* of the **Important Quality Features*** *so* necessary for high fidelity reproduction from records.

Before you choose a cartridge . . .

LISTEN AND COMPARE . . . demand 100% IQF*!

Feature	FLUXVALVE	Cartridge A	Cartridge B	Cartridge C
Frequency Response: Flat 20-20,000 cps ± 2 db (see curves on right)	YES 20 Points	NO 0 Points	NO 0 Points	NO 0 Points
Low Tracking Force, 2-4 grams	YES 20 Points	NO 0 Points	YES 20 Points	NO 0 Points
High Output, No Transformer Required	YES 10 Points	NO 0 Points	NO 0 Points	YES 10 Points
Replaceable Styli	YES 10 Points	NO 0 Points	NO 0 Points	YES 10 Points
½ Mil Stylus	YES 15 Points	NO 0 Points	NO 0 Points	NO 0 Points
One Cartridge For LP's and 78's	YES 5 Points	NO 0 Points	NO 0 Points	YES 5 Points
Anti-Hum Design	YES 10 Points	YES 10 Points	YES 10 Points	YES 10 Points
Hermetically Sealed	YES 10 Points	NO 0 Points	NO 0 Points	NO 0 Points
TOTAL POINT VALUE	100%	10%	30%	35%

FREQUENCY RESPONSE CURVES



Peaks and/or resonances in the stylus assembly at any recorded frequency will distort; and, damage the record groove. Therefore, any deviation from flat response over the recorded frequency band results in eventual breakdown of the groove wall. Deviations of from 3-6 db distort the record material as much as 60-100%.

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370-2D	2.7 mil Diamond	29.85
370-.5D	½ mil Diamond	35.85

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350-.5DD	½ mil Diamond	42.00
350-DS	1 mil Diamond/2.7 mil Sapphire	42.00
350-DD	1 mil Diamond/2.7 mil Diamond	54.00
350-D.5D	1 mil Diamond/½ mil Diamond	60.00

SERIES 3500 "T-Guard" STYLI**

S-3510	1 mil Sapphire	6.00
S-3527	2.7 mil Sapphire	6.00
D-3510	1 mil Diamond	18.00
D-3527	2.7 mil Diamond	18.00
D-3505	½ mil Diamond	24.00

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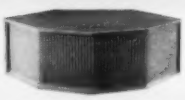

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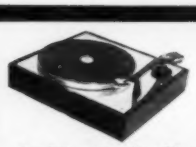

WEATHERS ML-1 Turntable

Announcing the new ML-1 "Synchromatic Drive" turntable designed especially for modern phonograph pickups having extremely wide range response and low tracking force. The turntable uses a synchronous motor with a newly developed drive system which features an extremely accurate speed of 33⅓ rpm. The turntable and motor are assembled on a metal motor board which is 14⅛" x 15⅛".

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ML-1 (on base) Price..... **$59.95**

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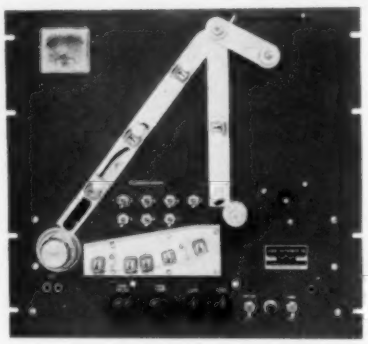
ai *electronic echo chambers*

Theatrical reverb for your pop records or spot announcements, natural sound for your TV musical background—wide flexibility!

2 instead of 10,000 cubic feet - *compact!*

Leading users of various models: Movietonews, National Film Board, WCFL, WFIL-TV, WGBH-TV, KCMO, WSB-TV, Australian Broadcasting System, Belgian Broadcasting System, Canadian Broadcasting Corp., Decca Records, Dumont, Howell Recording Studio, RCA Mexicana, Olmsted Sound Studios, Pathe-Marconi, RCA Far East, RCA Victor, Radio Free Europe, Radio Recorders.



JUST RELEASED !

New Model 44A

features 9 heads, individual head switching and sliding heads for infinite flexibility, variable equalization for special effects. Net price—$1485.

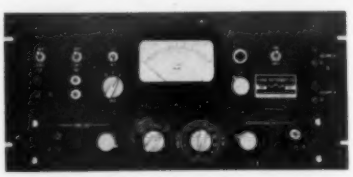
pays for itself in 3 to 5 months

leading manufacturers of quality audio equipment use

ai *intermodulation meters*

Flexibility, low cost, exceptionally low residual intermodulation (leakage).

Used by such leading equipment manufacturers as Admiral, Ampro, CBC, Boeing, Bogen, DuMont, Fairchild, GE, Langevin, Marantz, Radio Craftsmen, RCA, Seeburg, Sonotone, Standard Transformer, Stromberg-Carlson.



Do you know about our new Model 168, just released?

Write for new Catalog A-1

ai audio instrument co., inc.

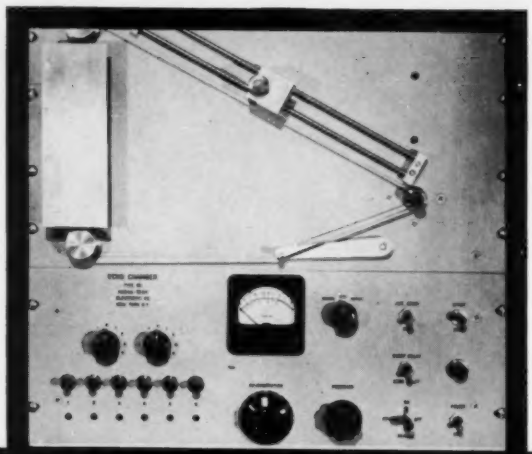
133 West 14 Street, New York 11, New York

NOW FROM MAGNA-TECH

Echo Chamber:

Six playback heads, closely spaced, each with its own level control and on-off switch, permit simulation of natural reverberation. Levels of individual heads can be set to follow decay curve. Includes VU meter, LF and HF equalizers, sliding head for special effects, and feedback control. Provision for remote control. Tape speeds 15 and 30 ips. Wide range of input and output levels.

Price: F.O.B. factory $1,360.00



Print-Through Eraser:

Erases print-through on ¼ inch tape, with negligible effect on response and level.

- Easily installed on Ampex 350 or 400 models.
- Push-button control allows automatic erase of tape print-through when playing back.
- Remote control box permits mounting on tape machine or mixing console.
- Variable print-through control provides unlimited range.

Price: F.O.B. factory $180.00

For further information

write to

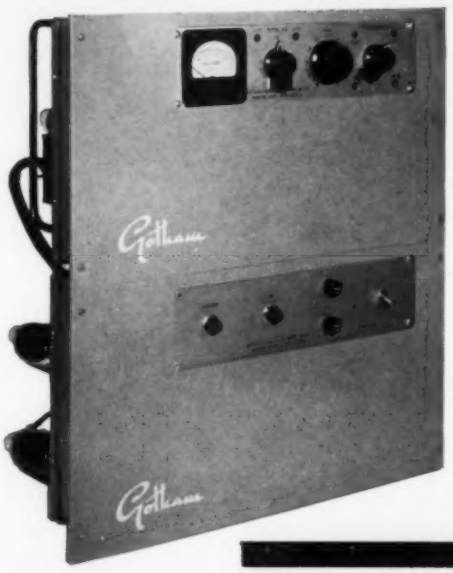
MAGNA-TECH

ELECTRONIC COMPANY

1600 Broadway New York 19, N. Y.

GRAMPIAN-GOTHAM

Feedback cutter system



Send for test record cut by the Grampian-Gotham Feedback Cutter System . . . professionally priced at only $4.00.

The GRAMPIAN-GOTHAM Feedback Recording System is a marvel of audio-engineering creativeness, producing the highest quality disc recordings known to date. Complete in every detail of equalization, pre-emphasis, and level correction for all three speeds, this unique system comes ready for instant mounting, turn-on, and operation without the necessity of recalibration, experimentation, etc. To operate the system requires only the sound source on one end and the lathe on the other.

It features the GRAMPIAN B1/D Feedback Cutterhead made in London, England; an improved version of the well-known BBC system. This superb cutterhead embodies an internal feedback winding which reduces distortion, flattens frequency response, and stabilizes operation over long periods of time and widely varying environmental conditions. Because it is damped through use of silicone damping fluid (Dow-Corning 200) with a leak-proof seal, temperature and age will not affect it, thus assuring constant performance.

TECHNICAL DATA

FREQUENCY RESPONSE
30 cycles to 15,000 cycles ±2 db. Down no more than 4 db at 20 cycles and 20,000 cycles.

TOTAL RMS HARMONIC DISTORTION
Below 1% at 1000 cycles measured at 7 cm/sec. peak recorded velocity (NARTB Standard Level).

MATCHING IMPEDANCE
16 ohms.

D.C. RESISTANCE
Main winding 3.7 ohms, Feedback winding 23 ohms.

INDUCTANCE
Main winding 1.65 MH.

TURNS RATIO
Main winding to Feedback winding 2:5 to 1.

***AUDIO POWER REQUIRED**
At 1000 cycles to record 7 cm/per sec. (2¾ inches/sec.) peak recorded velocity (NARTB Standard Level) - 1.25 watts or ±31 dbm.

STABILITY
Change in level less than 1 db from 60°F to 110°F.

STYLUS
Standard short shank ⅝ inches long.

DAMPING
Dow-Corning Silicone Fluid.

MOUNTING
Universal mounting for all lathes. Cover Plate tapped for mounting Fairchild Hot Thermo-Stylus.

* Frequency response measured with PFB-150WA Amplifier, balanced FM Modulator, and Buckman-Meyer Light Pattern.

The GOTHAM Recording Amplifier, PFB-150WA, is designed specifically to complement the GRAMPIAN Cutterhead in every respect. A masterpiece of precision, it is push-pull throughout for lowest even harmonic distortion and uses two 811-A Tubes as output triodes in conjunction with a toroidal output transformer which provides for low-distortion and transients during operation.

SPECIFICATIONS: GOTHAM PFB-150WA Power Amplifier

INPUT IMPEDANCE 150/600 ohms balanced or unbalanced. 5,000 ohms bridging - unbalanced. 2,500/10,000 ohms bridging - balanced.

INPUT LEVEL REQUIREMENT 16 dbm to +4 dbm for matching inputs (150/600). 0 dbm to +20 dbm for 2,500/5,000 ohm bridging. +8 dbm to +28 dbm for 10,000 ohms bridging. The above mentioned input levels are required at 1000 cycles to obtain 7 cm/sec. peak recorded velocity (NARTB Standard Level) on 33⅓ and 45 rpm positions, and approximately 15 cm/sec. peak recorded velocity at 78 rpm.

GAIN (600 ohm input) 46 db at 1000 cycles (Flat, 33⅓ & 45 rpm positions). 52 db at 100 cycles (78 rpm position).

FREQUENCY RESPONSE (Complementing Cutterhead to achieve RIAA recording curve ±2 db). RIAA Recording Curve within 1 db from 30 16,000 cycles in 33⅓, 45 and 78 positions, "FLAT" position above 1000 cycles within 1 db to 40,000 cycles. (screwdriver adjustments counterclockwise).

DAMPING FACTOR Better than 40.

RMS HARMONIC DISTORTION Less than 0.7% from 40 - 15,000 cycles at 150 watts. Less than 0.1% at 1000 cycles at 20 watts.

INTERMODULATION Less than 1% at 150 watts output (4:1 ratio 50/7,000).

SIGNAL-TO-NOISE RATIO 62 db below 1 watt (7 cm/sec. recorded velocity) 84 db below 150 watts.

POWER CONSUMPTION 115 volts 50/60 cycles; single phase; (220 volts supplied on special order). 2.8 amps at zero output; 5.5 amps at 150 watts out.

METERING 750 ma. direct-indicating plate-current meter.

CONTROLS 3-position plate-metering switch; 4-position equalization control; 2 db/step gain control; power switch; two line fuses.

TERMINALS Two 7-contact barrier strips; input and output.

TUBES 1 12AX7, 3 12BH7, 2 6BL7, 2 811-A, 2 3B28 (6BL4).

MOUNTING DIMENSIONS Two 19" standard rack units; 10.5" high each; maximum depth 11".

WEIGHT Amplifier unit 39 lbs; Power Supply 68 lbs. net

FINISH Light-grey Class "A" baked enamel; Cover Panels available in RCA umber-grey or black as desired. Control panels in natural brushed and anodized aluminum; engraved.

For complete data write to—

Reeves Equipment Corp.
10 East 52nd Street
New York 22, New York

FAIRCHILD

ARE YOU UP TO DATE ON THE LATEST AUDIO DEVELOPMENTS?

• Recording, Radio or TV Studios • Laboratories, Government Projects • Owners of Top Quality Sound Equipment ("Hi-Fi" or "Pro")

One or more of the following FAIRCHILD Quality Audio Products will improve your system. How many did you know about? Did you know, for instance, that

▶**FAIRCHILD** has built audio recording and reproducing equipment for over twenty years.

▶**FAIRCHILD** pioneered in both moving coil pickups and diamond styli. (Fairchild cartridges have always been supplied *only* with diamond styli.)

▶**FAIRCHILD** built its first commercial feedback amplifier in 1938.

▶**FAIRCHILD** makes more types of audio equipment than any other manufacturer.

▶**FAIRCHILD** offers a special engineering service in adapting its products to other specific uses.

▶Established firms can try any **FAIRCHILD** equipment on a no-risk basis. Write for details on your company letterhead.

MOVING COIL CARTRIDGES

the most famous FAIRCHILD product

FAIRCHILD has concentrated on building not the cheapest but the BEST. Most of its cartridges have been of the moving-coil type for both lateral and vertical recordings.

Today's FAIRCHILD moving-coil pickups are the best ever made, and feature *exceptional ruggedness* in spite of *extremely high compliance* (both lateral and vertical) necessary for minimum record wear, and unequalled listening quality. Vertical compliance is comparable to that of stereo pickups. Triple gold plated wire is used to insure complete resistance to coil failure in any atmosphere. Lugs are gold plated to insure 100% reliable contact. Unique damping system and flexure pivot construction produce unexcelled transient response.

When you choose a FAIRCHILD pickup, you obtain the best in sound quality, the least hum pickup, adequate output (5 mv) without transformer, low impedance output, complete reliability.

LATERAL TYPES 225A—Latest model microgroove cartridge—1.0 mil diamond. Impedance 200 ohms, output 0.8 mv/cm/sec **net $37.50**
225B—Same as above but 2.5 mil diamond **net $37.50**

XP-3—Custom-built, special microgroove design. 0.7 mil diamond. Uses sub-miniature coil, air damping, extremely compliant mounting. Exceptional performance in clarity, separation and tracking ability. Output 0.4 mv/cm/sec **net $60.00**

VERTICAL TYPES 216A—For vertical recordings only **net $60.00**

STEREO XP-4—Newest design moving-coil stereo pickup for the 45/45 system. Available March, 1958. **net $79.50**

603—Stereo Pickup. Special design, dual rotating coil pickup for stereo disks (45/45 system). Supplied only in arm as complete system. May be used as vertical or lateral pickup merely by turning switch (supplied). Immediate delivery **net $250.00**

ACCESSORIES 235—Transformer. May be used with any of the above or with other 100-200 ohm low level sources. Voltage gain 14 db. Hum shielding better than 90 db. Uses RCA type phono jack input and pigtail output with shielded single conductor RCA type phono plug **net $13.75**

XP POLICY FAIRCHILD has for about a year been sharing its latest developments with the public by releasing its newest designs as XP products. These are usually hand made, always on short run production, and generally at a premium price. The policy has been extremely well received and we welcome inquiries on XP products, or we will gladly put you on a new-product mailing list.

ARMS

Here again FAIRCHILD has been a leader in research and design, and FAIRCHILD arms are widely acknowledged to be of superior design, workmanship and performance. A GOOD arm is fully as essential as a GOOD cartridge.

TYPE 202—Designed expressly for the professional. Features turret head construction accepting 3 FAIRCHILD (only) cartridges. Automatic stylus force adjustment for different cartridges. Silicone damping for horizontal movement only. Automatic temperature compensation keeps damping constant. Extremely rugged and reliable. **net $99.00**

TYPE 280A/281A—These arms feature the most convenient front end available with plug-in cartridge carriers. Supplied also with stereo plug-in feature, accepting also standard cartridges. Laterally balanced, thumb screw adjustment for stylus pressure, instrument gyro pivots and many other quality features. Low basic resonance frequency, no torsional resonances. No arm compares in convenience and performance to these plug-in types.
280A—for records up to 12" **net $37.50**
281A—for records up to 16" **net $47.00**

TURNTABLES

In turntables FAIRCHILD draws on its experience in designing precision machinery of many types, including disk recorders, tape recorders of the highest quality, and professional playback machines as well as other related equipments. FAIRCHILD's most recent development is the ELECTRONIC DRIVE, a variable frequency power supply of great stability, suitable for operating synchonous motors smoothly and with extra precise, positive speed control. (Special models available for professional use and other applications —see below) ELECTRONIC DRIVE also

eliminates stringent power line requirements. Tables will run perfectly on 40-400 cycle power, vibrators, inverters, etc.

The 412-series tables are 12" units, suitable for broadcast and home installations. The 512 units are supplied mounted in studio cabinets, with or without electronics and/or arms. All feature two stage belt drive with isolated intermediate pulley and *no rubber pucks*. Torque is adequate for using these tables for record cutting. Rumble is comparable to that of the best recording lathes. Ideal for playing lateral, vertical or stereo records.

TYPE 412-1—Basic unit, hysteresis motor, 33⅓ RPM. Will accept 412 E/D power supply to operate at 4 speeds. **net $99.50**

TYPE 412-2—Two-speed unit, 33⅓ and 45 RPM, hysteresis motor. Not designed for use with ELECTRONIC DRIVE. Available March, 1958. Price to be announced.

TYPE 412-3—16⅔, 33⅓ and 45 RPM operation, hysteresis motor. Available March, 1958.

TYPE 412-4—Complete **ELECTRONIC DRIVE** turntable, hysteresis motor, featuring all-electronic operation. 4 speeds, adjustable ±3% at any speed setting. **net $229.50**

TYPE 412E/D—ELECTRONIC DRIVE (variable frequency power supply) only. May be added to 412-1 to convert it to 412-4. Long term speed accuracy ±.3%. Basic frequencies 30, 60, 81, 141 each ±3% by potentiometer control **net $135.00**

All of the above meet or exceed following specifications measured according to NARTB Recording and Reproducing Standards (June, 1953). RUMBLE: 41 db below 1.4 cm/sec (6 db better than Broadcast requirements). WOW & FLUTTER: .1% (Broadcast requirement .2%).

TYPE 512-2—Special adaptation of 412-2 for broadcast use. Shock mounted and sound insulated cabinet of standard dimensions. Exceeds all NARTB specifications. Available March, 1958.

TYPE 512-4—Special adaptation of ELECTRONIC DRIVE to broadcast use. Shock mounted and sound insulated cabinet of standard dimensions. Exceeds all NARTB specifications. **net $387.50**

TYPE 530G—Well-known FAIRCHILD broadcast turntable, completely re-engineered for greatly improved performance and silent operation. Features entirely new shock mounted suspension system, new vibration-isolating drive couplings, improved motor assembly. Retains 3-speed operation (33⅓, 45 and 78 RPM) with instantaneous speed shift, completely synchronous operation. Heavy-duty construction for continuous service, and many other features. **net $629.50**

ELECTRONICS

TYPE 245—PREAMPLIFIER. A completely new preamplifier meeting all professional standards of performance. Inputs for low impedance cartridges (equalized), tape heads (3¾, 7½ and 15 ips), or high level. Gain 54 db, S/N 66 db on phono input (reference 10 mv in at 1 kc). Will accept up to 300 mv (1 kc) on low-level input without overloading. Output 3000 ohms. Distortion 0.1% at 2 volts, 1% at 20 volts output. Uses Allen-Bradley volume control, EF86 triode input stage, giving equivalent input noise 2-4 microvolts. Quality components throughout. White noise exceptionally low on tape head input channels. Designed to work with numerous plug-in accessories, adapting basic circuit to many uses. **net $119.50**

TYPE 246—PREAMPLIFIER. Provides additional controls and flexibility, same high quality performance as Type 245. Includes high and low pass filter sets (sharp cut-off) "presence" control, "loudness" control. **net $179.50**

TYPE 247—STEREO CONVERTER. Converts two 245 preamplifiers to a stereo unit with overall gain control, plus complete individual channel control.

TYPE 255A—AMPLIFIER. 30-watt Amplifier for monitor or other use. Exceptional stability, full power output 20 cps to 20 kc. Vanishingly small odd-harmonic distortion results in excellent triode-like quality. Uses EL34 output tubes very conservatively operated. Input impedance 100,000 ohms. Output 8 and 16 ohms. Adopted by several quality recording studios for standard monitor amplifier as the result of instrument and listening tests. Also ideal for hi-fi or any basic amplifier use. May be obtained for rack mounting at slight extra cost. An exceptional value. **net $124.50**

TYPE 345—PREAMPLIFIER. Similar to Model 245 but has 600 ohms output through transformer. For rack or cabinet mounting.

SPECIAL PRODUCTS AND SERVICES

FAIRCHILD also provides special engineering services and, in some cases, special adaptation of existing products to other uses. Some examples are:

127/128 TAPE RECORDER—Latest version of the famous 100 series recorders for professional audio, facsimile, data recording and similar uses. Highest performance available today. Particular attention given to special requirements.

141C CONTROL TRACK GENERATOR. Provides sync signal for adapting any tape recorder for use with the FAIRCHILD PIC SYNC SYSTEM. **net $150.00**

539K3 CONSOLE DISK RECORDER. A console-type recorder operating at 33⅓, 45 or 78 RPM.

550—ELECTRONIC DRIVE DISK RECORDER. Extremely high quality recordings may be made, independent of power source stability. Speed adjustable for exact line frequency or variable to compensate for varying tape speeds. Also with automatic variable pitch feature. Available Fall, 1958. Write for further information.

660—LIMITER—for broadcast or recording studio use. New design featuring variable and selective time constant. Complete absence of thump. Negligible distortion under all operating conditions. Extreme ruggedness and reliability. **net $850.00**

690 series—VARIABLE FREQUENCY POWER SUPPLIES for special applications. Not torque-sensitive; fully synchronous. Applicable to speed control for recording machines, gyro production testing, shake tables, many other uses. Ratings up to 250 watts. Write for quotation.

WOW & FLUTTER METER. Extremely stable and accurate unit for laboratory or production testing. Uses 3 kc test tone. Peak-to-peak indicating by meter or chart. Accurate response DC to 150 cps flutter rates. Self-contained DC amplifier. 6½" × 14" × 15"—19 lbs.

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Fairchild Recording Equipment Corporation

Application Engineering Department

10-40 45th Avenue

Long Island City 1, New York

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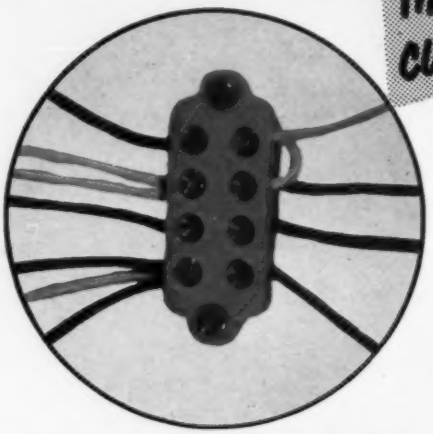

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Jet speed assembly—One operation required.
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TWO CHANNELS OF IDENTICAL SOUND QUALITY IN ONE GROOVE

The Westrex 3A Feedback Cutter records and The Westrex 10A Moving Coil Pickup reproduces

two 45-degree recordings of identical sound quality in a single groove, using a single stylus which is actuated by two separate sound channels.

The Westrex StereoDisk Recorder will also cut vertical-lateral stereophonic, standard lateral or vertical records.

Provision for Hot-Stylus recording is included.

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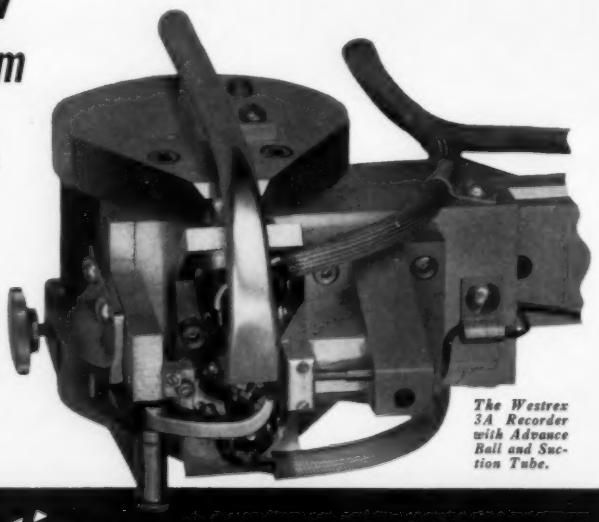

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Westrex Corporation

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